A FRAMEWORK FOR DEVELOPING, MANUFACTURING, AND SOURCING TRUCKS & EQUIPMENT IN A GLOBAL FLUID MANAGEMENT INDUSTRY

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Submitted to the MIT Sloan School of Management and the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degrees of

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AND
Master of Science in Civil and Environmental Engineering

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ABSTRACT

Selecting and executing the optimal strategy for developing new products is a non trivial task, especially for low volume, high complexity products in a highly volatile global industry such as Fluid Management. At Fluid Management Corporation (FMC), Trucks and Equipment (T&E) that are used to deliver services both onshore and offshore currently follow a single product development model: In-house design; Outsourced prototyping, testing, and manufacturing.

The objective of this research work is to challenge the status quo and to provide FMC with a practical framework that helps to determine the optimal development strategy. Rather than following a single development strategy for the entire portfolio of trucks and equipment products, the new methodology recommends a development strategy at a product functionality level and product feature level.

Product development strategy is defined here using three dimensions: Design strategy; Manufacturing strategy; and Supply Chain strategy. Each functionality or feature is evaluated using a set of six criteria which then maps that functionality or feature to a specific recommended location on a three dimensional strategy cube. The set of evaluation criteria were derived from exploring and analyzing the current product development process, and from benchmarking world class companies from a wide range of different industries.

The results show that for functionalities and features that differentiate FMC from its competitors and are viewed as core competencies, FMC should consider in sourcing the design, prototyping, and testing processes. These functionalities include blending, pumping, software development, and system integration. Similarly, for functionalities and features that are not viewed as core competencies such as transport units, storage, and power generation, FMC should consider outsourcing the development process including design.

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Many of my peers from the LFM class of 2009 were instrumental during my research and benchmarking studies. I would like to recognize: Nathan Peck, David Hsu, Ryan Lester, Clayton Poppe, and Jon King for their help and advice.

Finally, I would like to thank my wife Mikell, daughter Myrrah Belle, and our entire family. Without their unconditional love and support, I would not have been able to achieve this tremendous accomplishment.

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BIOGRAPHICAL NOTE

Ghassan Awwad was born in Amman, Jordan. He attended the University of Jordan and received a BS in Industrial Engineering. Upon graduation, Ghassan moved to Texas where he attended Texas A&M University and received a MS in Industrial Engineering. While at Texas A&M, Ghassan was a graduate research assistant for the Texas Manufacturing Assistance Center and the Industrial Engineering department, he completed his Master's thesis entitled "Applying group technology in the operational planning of electronics assembly, multiple machine case".

Ghassan started his professional career with Dell Incorporated in Austin, Texas. His experience included work in process engineering, logistics, supply chain management, and fulfillment engineering. Prior to attending the Leaders For Manufacturing program at MIT, Ghassan managed a team of process engineers responsible for supporting strategic and tactical initiatives in five distribution centers. Ghassan is a lean change agent and six sigma green belt certified engineer. Upon graduation from MIT in June 2009, Ghassan will join Spirit Aerosystems in Wichita, Kansas, as a Supply Chain Manager.

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GLOSSARY

3DCE: Three Dimensional Concurrent Engineering
BOM: Bill of Materials
CBA: Cost Benefit Analysis
CM: Configuration Management
CNC: Computer Numeric Control
CRT: Cathode Ray Tube
DFA: Design for Assembly
DFM: Design for Manufacturability
DOT: Department of Transportation
ECO: Engineering Change Order
ECR: Engineering Change Request
FMC: Fluid Management Corporation
FSG: Fluid Services Group
IP: Intellectual Property
JIT: Just in Time
KPI: Key Performance Indicator
LCD: Liquid Crystal Display
LFM: Leaders for Manufacturing
PC: Product Champion
PM: Project Manager
PMO: Program Management Office
PMP: Project Management Professional
QHSE: Quality, Health, Safety, and Environmental
SME: Subject Matter Expert
T&E: Trucks and Equipment
TFT: Thin Film Transistor
VMI: Vendor Managed Inventory

1 Introduction

In this chapter, I will provide a brief background about Fluid Management Corporation (FMC) and introduce the organization that sponsored this research work, Fluid Services Group (FSG). I will also present the background and objective of the project and the approach that I followed to conduct my research.

1.1 Company Overview

FMC is a multi-billion dollar Fluid Management company supplying technology, project management, and information solutions to the Fluid Management industry. Fluid Services Group (FSG) develops Trucks & Equipment (T&E) used by Field Operations. The different functional groups within FSG include:

- Research & Development
- Design Engineering
- Manufacturing Engineering
- Sustaining Engineering
- Supply Chain Management
- Quality, Health, Safety, and Environmental (QHSE)
- Technical Support

Field Operations utilize T&E products to perform two primary services: Cementing Fluid Management and Mobile Pumping. For onshore applications, the equipment is normally mounted on a float or a truck while for off shore applications, the equipment is normally mounted on skids. The characteristics of T&E products are low volume, high complexity, and high variability.

With the goal of standardizing the process of developing new products to be able to achieve the vision of "Design Anywhere, Manufacture Anywhere", collaboration and knowledge transfer between the different stakeholders become crucial.

1.2 Project Background

Historically, the design and manufacturing of T&Es was done in house. However, due to the cyclical nature of the Fluid Management industry, FMC made a strategic decision in the early 1990s to outsource prototyping, testing, and manufacturing of its T&E products to local as well as global suppliers. A typical new product is designed by FSG's engineering team, after that a supplier is selected to build the first article or prototype that will be tested first at the supplier's site then in the field.

Prototype suppliers (or integrators) are small machine shops owned for the most part by ex-FMC employees. These shops are setup in a typical job shop layout. Some with fabrication capability (CNC machines) while the rest of the integrators perform manual assembly processes only (welding and joining). Most of the vendors are located in the United States.

Historically, prototype suppliers were awarded production volumes after the initial prototype and pilot units pass all tests successfully and are commercialized. The role that the prototype suppliers play is not limited to the assembly of products. They are considered subject matter experts due to their extensive experience in the industry in general and with FMC products specifically. They also have established relationships with field engineers, design engineers, and manufacturing engineers. They not only critique designs and redline drawings, but also communicate field requirements and reliability information back to the manufacturing and sustaining engineers.

1.3 Project Objective

The objective for this project was to assess, benchmark, and recommend improvements to the Product Development process that FSG uses to design, manufacture, and source Trucks & Equipment. The scope was limited to large products with development budget that exceeds $2M each.

1.4 Approach

I decided to follow the following approach in conducting my research:

- Review the formal FMC product development process
- Explore and document the current product development process by interviewing key stakeholders and by visiting suppliers
- Benchmark world class companies from different industries and identify key lessons learned that are applicable to FMC
- Develop a framework to evaluate product functionalities and design features based on pre-determined set of criteria
- Create a decision-making tool to determine the optimal Design strategy, Manufacturing strategy, and Supply Chain Strategy for each functionality and design feature
- Define future state and make recommendations

2 Current State

In this chapter, I will review the theoretical product development process at FMC and compare it to actual current and past practices. I will also highlight some issues that are associated with the current product development process from the perspective of key stakeholders. The chapter concludes with an organizational review and stakeholder analysis.

2.1 Theoretical Product Development Process

In theory, a typical product development project should follow the process depicted in Figure 1 below. The idea is to design the product, process, and supply chain concurrently. While prototyping and testing are outsourced, feedback mechanisms should be in place to capture, document, and communicate lessons learned and design changes. FSG engineers should be able to hand over the design package to the production supplier who is in responsible for building all production units past commercialization.

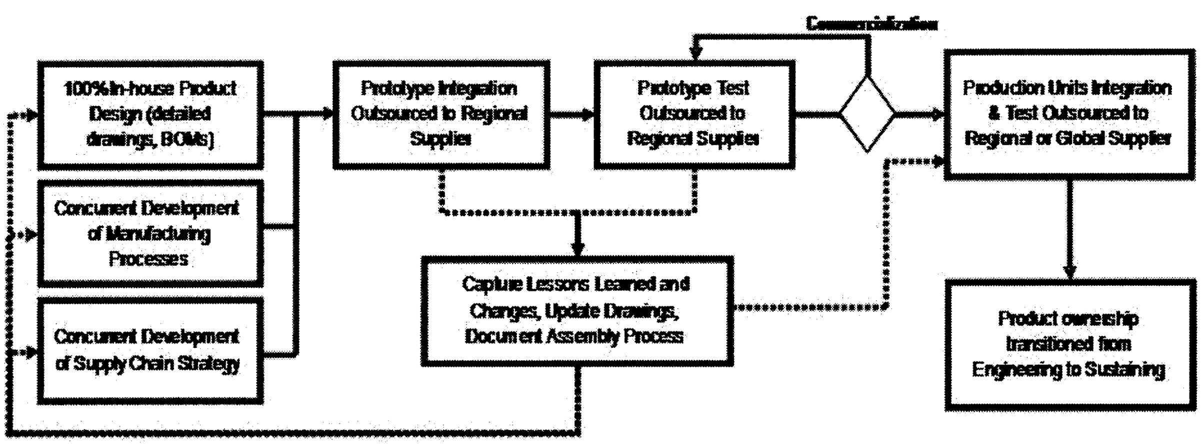

Figure 1: Theoretical Product Development Process for T&E Products

2.2 Actual Product Development Process

Having worked very closely with a team that is currently working on a large product development project for a new Cement pumping unit, and having interviewed key stakeholders of several previously completed T&E projects, I observed that the actual product development process as depicted in the Figure 2 below deviates from the theoretical product development process.

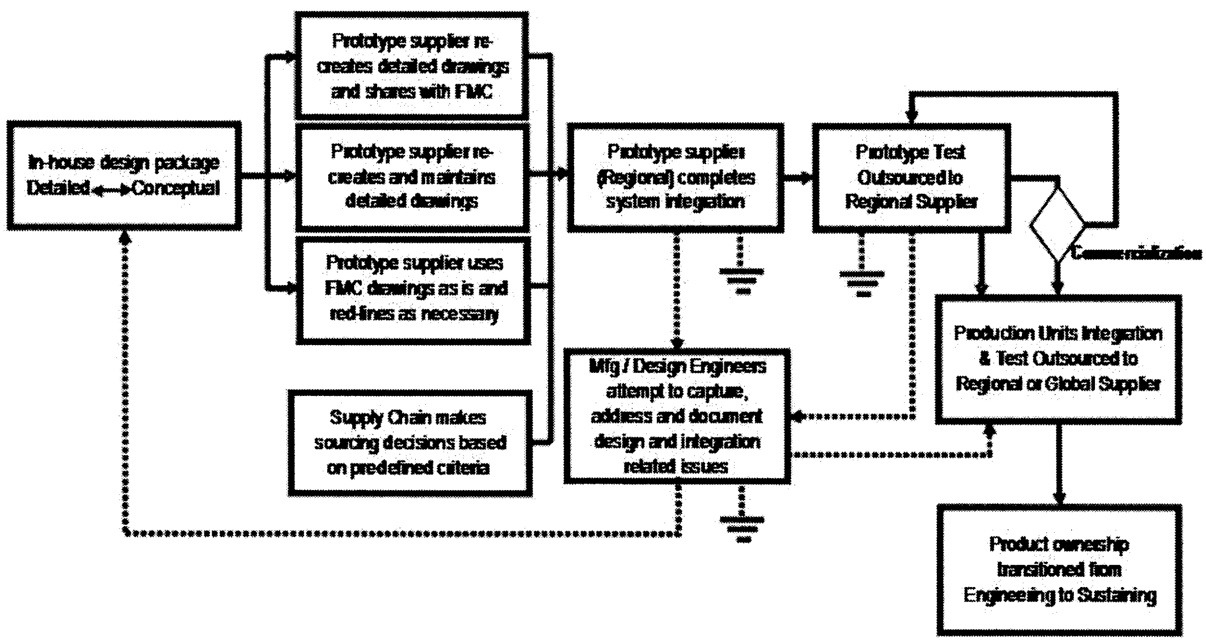

Figure 2: Actual Product Development Process for T&E Products

2.3 Issues with Current Process

There are several issues with the current product development process. Some of these issues are:

1. Level of detail in design drawings provided by FMC design engineers to prototype suppliers varies significantly from project to project. As a result, three different design methodologies have evolved over time:

   a. Prototype supplier re-creates detailed FMC drawings in order to provide sufficient level of detail for manufacturing, and then shares the drawings back with FMC

   b. Prototype supplier re-creates detailed FMC drawings in order to provide sufficient level of detail for manufacturing without sharing the new drawings with FMC in order to maintain ownership of design
   c. Prototype supplier uses drawings provided by FMC as is to start prototype assembly. When design issues such as interferences arise, supplier red-lines hard copy of design drawing and sends back to FMC for update

2. High turnover rate and limited manufacturing and field expertise cause new product development teams to rely heavily on local suppliers with established relationships and tacit knowledge of T&E products to complete designs and define integration processes
3. Loss of tacit knowledge and on-the-job learning while attempting to capture lessons learned during prototype build and test
4. Loopholes around the formal product development process such as scope creep and the ability to move into production phase without formal product commercialization
5. Late engagement, limited expertise, and lack of control over suppliers' processes by the manufacturing engineers result in minimal influence on product or process design
6. Current sourcing strategy and supplier qualification processes are mainly tied to supplier financial metrics rather than technical capabilities
7. Full transition of product ownership from design engineering to sustaining engineering once a product is commercialized results in lack of project continuity. This problem is further highlighted when project documentation is incomplete (i.e. missing training manuals or old versions of design drawings)
8. Field engineers and technicians contact equipment suppliers directly to address warranty related issues in order to expedite the repair process. As a result, design, manufacturing, and sustaining engineers are kept outside the loop and do not benefit from knowledge sharing and lessons learned in order to improve the design of future products

2.4 Stakeholder Analysis

The Stakeholder diagram below depicts the different groups involved in the product development process, and the interactions between these groups. As an added level of complexity, FMC follows a "Matrix" organizational structure. Each employee has a direct manager to whom he/she reports and a functional manager to whom he/she is accountable.

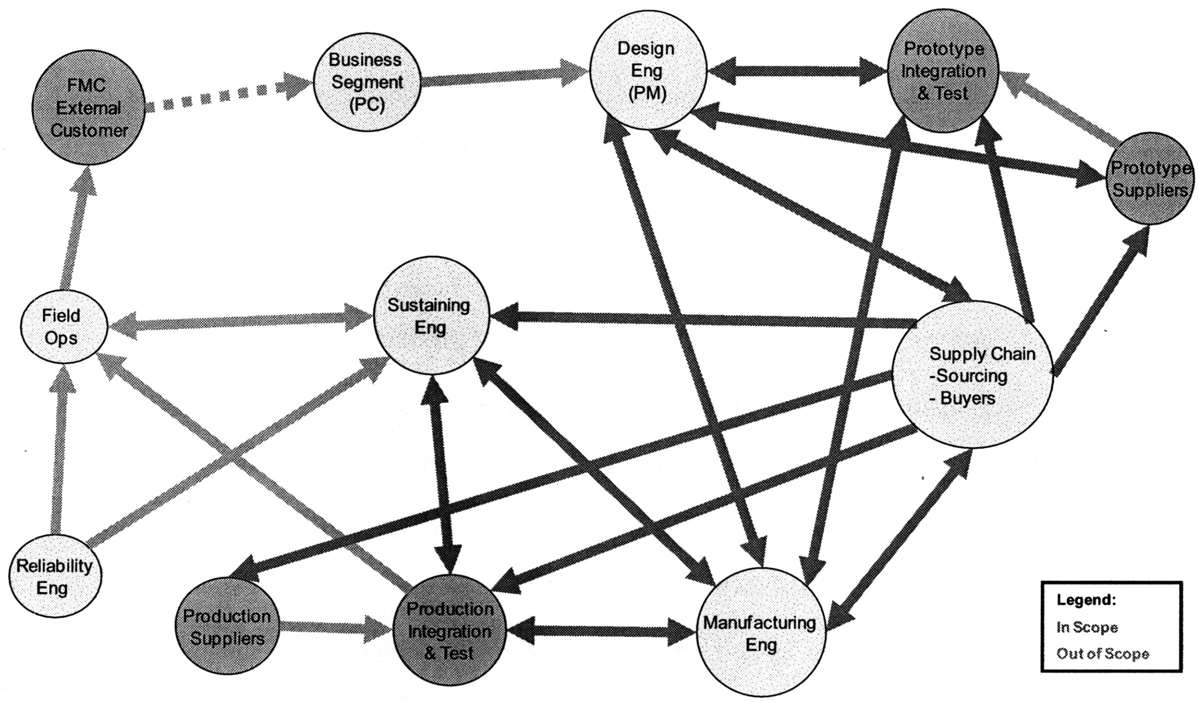

Figure 3: Stakeholder Diagram

While interviewing members of the different teams, one of the first observations that I made was that the incentives of the different groups did not appear to be aligned. Each group has its own set of goals and objectives that it is measured against during review period. The design engineering team is measured against its ability to develop products on time and on budget while the sustaining and manufacturing engineering teams are ultimately measured against the quality performance of the products in the field.

In addition to no alignment of incentives, there is also no single point of accountability. The responsibility of the design engineering team, and the project manager who is a member of the design engineering team, ends once a product is commercialized and deployed in the field. At which point the responsibility is handed over to a sustaining engineer who is left to deal with all the open issues related to the product.

One potential solution is to define a set of common success metrics for each project, then link these metrics to the performance and incentives system of each member on the project team. The objective would be to establish a common goal that all members of the project team march towards.

Another recommendation is to address the misalignment in organizational structure. While the design engineers report directly to the project manager, who is a senior design engineer, the rest of the project team members report to their own functional managers. The two chains of command only intersect at the highest level of the organization which is a very senior position. One potential solution is to establish a Program Management Office (PMO) staffed by professional project managers (PMPs) and have all member of the project team report (at least functionally) to the project manager. This structure will group design, manufacturing, sustaining, and supply chain under one umbrella.

There are two distinct sub-cultures within the organization. The first one, which is exhibited mainly by the design engineering team and is consistent with the rest of the company, is a culture of Technology. Most design team members have Masters or PhD degrees in Mechanical, Electrical, or Chemical Engineering. They come across as very qualified, highly technical engineers who prefer to work individually. Meetings and other forms of communication are kept to a minimum.
The second sub-culture that I observed is exhibited by the rest of the organization (manufacturing, sustaining, and supply chain). It is a culture of Fire Fighting. While most team members have technical engineering degrees, they spend most of their time handling tactical day-to-day issues such as issuing Engineering Change Orders (ECOs) or chasing missing parts.

3 Literature Review

This chapter provides a brief literature review of topics related to this research work such as new product development strategy, global sourcing, concurrent engineering, and supplier relationships.

3.1 Three Dimensional Concurrent Engineering

The concept of Three Dimensional Concurrent Engineering (3DCE) was first introduced by Professor Charles Fine in his book *Clockspeed* in 1998. It is defined as: "the simultaneous development of products, processes, and supply chains" (Fine, 1998). Historically, the product development process at FSG followed a sequential development of product, process, and supply chain. A successful implementation of 3DCE requires early engagement of a true cross-functional team including early supplier and customer engagement (Birou & Fawcett, 1994).

Some of the benefits of concurrent engineering include: time-to-market reduction, cost reduction, quality improvement, and improved customer satisfaction (Balasubramanian, 2001) (Koufteros, Vonderembse, & Doll, 2002) which are all considered key business metrics at FMC. Involvement of both top management and functional leadership is needed to effectively implement 3DCE (Ellram, Tate, & Carter, 2007).

3.2 Supplier Relationships in Product Development

Since competitiveness is the ability to develop innovative products at a lower cost and faster than the competition (Pralahad & Hamel, 1990), it is essential to proactively integrate suppliers into the new product development process and promoting their input into the new product development process (McDermott & Handfield, 2000). Successful buyer-supplier relationships are based on trust. There are several factors that can result in a higher level of trust between buyers and suppliers including longer duration since the first transaction, greater face-to-face interactions, and continuous repeated exchange between the buyer and the supplier (Dyer & Chu, 2000).

Key characteristics of Japanese-style buyer-supplier partnerships are (Wasti & Liker, 1999):

- Long-term relationships and commitment
- Frequent communication
- Minimize total value chain costs and improve quality
- Significant investments in equipment, technology, and personnel
- Sharing of technical and cost information
- Trust-building practices such as stock swapping and resource sharing

Buyer-dependence, supplier human asset investments, and trust are all positively associated with improved supply chain responsiveness, which is the ability of the supplier to quickly respond to the buyer's needs (Handfield & Christian, 2002).

3.3 In sourcing/Outsourcing Decision

The concept of core competence and capabilities was observed as a key issue in effectively making in sourcing/outsourcing decisions. As technologies get more complex, firms may focus their internal resources on some core aspects of the technology while depending on strategically outsourced innovations to complement their efforts (McDermott & Handfield, 2000).

When considering outsourcing at a strategic level, the value chain expresses the necessary processes and order flows for delivering goods and services to customers. Each part of the value chain should not only contribute by fulfilling its function, but also employ control mechanisms suited for meeting overall performance requirements (Dekkers, 2000).

4 Benchmarking

The goal of this chapter is to analyze the product development strategy of world class companies, and to capture key lessons learned that are applicable to FMC.

4.1 Methodology

With the objective of developing a better understanding of how world class companies determine their optimal strategy for developing new products, a set of twelve companies representing five different industries were selected. Table 1 below lists the different companies used in the benchmarking exercise.

Industry	Product Line / Program	Companies
Consumer Electronics	LCD TV	Sharp, Sony, Samsung
Personal Computers	Desktops and Laptops	Dell, Apple
Automotive	General	Toyota, General Motors, Nissan, Chrysler
Aerospace	737, 787	Boeing
Heavy	General	Caterpillar, ABB

Table 1: List of Industries and Companies Selected for Benchmarking Study

A set of Key Performance Indicators (KPI) was then determined for each company. The KPIs included metrics such as:

- Revenue
- Percentage of Research & Development (R&D) spend to Revenue
- Revenue per employee
- Worldwide market share

Primary and Secondary research was conducted on each company. Primary research resources included own work experience, site visits, interviews with current and former employees, and interviews with current LFM interns. Secondary research resources included published articles, periodicals, previous LFM theses, and internet research. The findings of each case study were the analyzed and translated into lessons learned and recommendations applicable to FMC.

4.2 Focus

The focus of the benchmarking study was to analyze the product development strategy for each company using a three-dimensional approach as depicted in Figure 4 below:

1. Design Strategy: Is the detailed design work being done in house or does the company provide high-level design specifications and then outsource detailed design?
2. Manufacturing Strategy: Does the company prototype, test, and manufacture its products in house or does it outsource all or some of these activities?
3. Sourcing Strategy: Does the company partner with a limited number of global suppliers or does it rely on a large base of local and global suppliers?

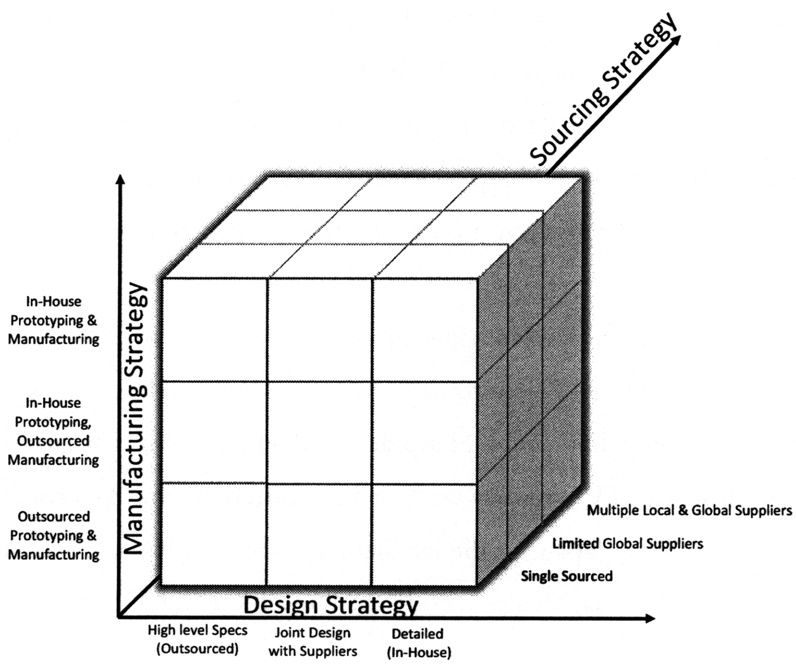

Figure 4: Three-Dimensional Approach to Benchmarking

4.3 Case Studies

4.3.1 LCD TV Industry

Sharp, Sony, and Samsung are considered the top three suppliers of LCD-TV products worldwide with a combined market share of 43% (Nakata, 2007). As of 2008, the market share of each of these three companies was as follows:

- Sharp: 12% Worldwide, 48% Japan
- Sony: 15% Worldwide, 18% Japan
- Samsung: 16% Worldwide, 0% Japan

While all three companies are considered to be very successful, they each followed a totally different strategy when it came to developing and manufacturing LCD-TV products.

Sharp is considered the industry leader. It developed and commercialized the LCD-TV technology and it followed a fully vertically integrated model starting from Thin Film Transistor (TFT) fabrication to LCD-TV complete assembly. Sharp considers the capability to design, fabricate, and assemble LCD-TV products in house under one roof in Kameyama, Japan to be "Core Competency" and a clear differentiator. Sharp's main focus was on the Japanese market, thus the 48% market share. When the rest of the world started switching from traditional CRT technology to LCD-TV technology, Sharp initially wanted to maintain its global strategy by establishing a second vertically integrated plant in Kameyama, Japan, in order to meet the rapid growth in demand. However, demand grew much faster than Sharp anticipated and the outbound logistics cost of shipping such bulky and heavy products all over the world became prohibiting.

In order to stay competitive, Sharp decided to adjust its global strategy in order to maintain its competitive edge and better serve its global customers. Since the design, fabrication and assembly of LCD panels were considered core competency, Sharp decided to keep them centralized in Japan to serve all global markets. However, TV assembly was not a key differentiator. As a result, Sharp decided to maintain TV assembly in Japan for the Japanese market only. It also established regional TV assembly plants in China, Malaysia, Mexico, and Poland to fulfill LCD-TV products to the rest of the world.

Contrary to Sharp, Sony's core competency was its superior CRT technology (the Vega image engine). Sony also had strong brand name recognition with its (Trinitron) TVs. With the global transition from CRT technology to LCD technology, Sony had three choices:

1. Try to fight the switch from CRT to LCD by lowering the price of its CRT-TV products and compete head to head with Sharp. This strategy was very risky because LCD technology clearly provided superior picture quality, and the high price tag of LCD-TVs was destined to decrease as the new technology matures.
2. Try to catch up with Sharp by investing heavily in LCD R&D and fabrication capability. This strategy was also risky because Sony may not be able to close the gap with Sharp in an industry where time-to-market is crucial. In addition, R&D and fabrication capability require massive capital investment.
3. The third option that Sony had was to identify a strategic partner with existing LCD panel fabrication capability in order to secure a reliable source of LCD panels. Sony can then leverage its brand recognition and its core competencies (Vega image engine and TV assembly) and replace the old CRT displays with LCD displays.

Sony decided to proceed with option 3. It identified a perfect partner that met all of its criteria, Samsung. Samsung had in-house LCD-TV capability and experience in system integration. It also had invested a huge sunk cost in system integration capacity. In 2005, Sony and Samsung established a joint venture (S-LCD Corporation), a $1.8B capital investment that secured a stable supply of LCD panels. Sony and Samsung also planned to invest an additional $18B in their joint venture by the year 2015 (Nakata, 2007).

The key lesson learned from benchmarking the LCD-TV industry that I believe is applicable to any industry is the importance of understanding and focusing on one's core competency and leveraging that core competency to differentiate your products from your competitors' from the perspective of the customers. This study also highlights the importance of not only having a well defined global strategy as it related to product development, but also the importance of having the flexibility to adjust and modify the strategy as market conditions and customer requirements change with time.

4.3.2 Personal Computers Industry

When it comes to designing, manufacturing, and distributing personal computers, Dell and Apple could not be any more different. Yet, each company individually is viewed as a true success story and has played a major role in revolutionizing the industry.

Dell built its business model on the direct relationship with its customers. It eliminated the middle man and built custom made PCs configured to order by customers. Dell's core competency is operational excellence. The key elements to Dell's operational efficiency are:

- Low inventory level and vendor managed inventory
- Negative cash conversion cycle
- Just in time lean production system close to customer locations
- Build and configure to order production system
- Optimized Inbound and Outbound Supply Chain networks

Dell's model lends itself very well to service commercial customers such as large, medium, and small businesses, educational institutions, and government agencies. The commercial business at Dell represents 85% of total revenue. The other 15% of revenue is attributed to the consumer business. While Dell does very limited product development in-house (R&D spend as a percentage of revenue is 1%), it relies heavily on its suppliers and competitors to develop new products with standardized technology and modular components. Dell's role is to take a standard product and figure out how to make it faster and cheaper. Another benefit of the Dell model is the ability to shape demand by adjusting promotional offerings real time based on actual inventory levels of parts. Dell has a 13.6% Worldwide PC market share and 29.5% US PC market share.

The relationship between Dell and its suppliers is very transactional. Each standard component (commodity) is multi-sourced. Dell defines quality requirements for each component and then bids the business (sometimes once a quarter) via an online reverse auction tool to ensure lowest cost. As a result, Dell finds itself working with a relatively large supply base that requires a lot of coordination.

Apple on the other hand is very focused on designing and developing its own proprietary products in-house (both hardware and software). Its main business revolves around consumer products tailored towards a niche market and a loyal customer base that is willing to pay a premium to own an Apple PC. Apple's core competency is superior industrial design capability. R&D spend as a percentage of revenue is 3.4% compared to Dell's 1%. Apple uses only proprietary components and processes to design its products which are not compatible with other products manufactured by competitors. That level of product differentiation is viewed by Apple as a competitive advantage. Apple's Worldwide PC market share is 3.2% and US PC market share is 9.5%.

Unlike Dell, Apple partners with a small set of suppliers based out of Asia to fully outsource manufacturing. Due to the unique process requirements to manufacture Apple products, Apple invests substantial amount of capital in order to build its suppliers capabilities. As a result, the relationship between Apple and its suppliers tends to be long term and required much higher level of collaboration and coordination than the relationship between Dell and its supply base.

Both companies have been facing key challenges in recent years. In the case of Dell, commercial PC demand has been growing at much slower rate than it did in the 1990s while consumer demand is growing fast and is shifting from desktops to laptops. In order to cater for consumers, Dell has to invest significant resources to build up its R&D and product design capabilities. Apple however is growing at unprecedented rate which poses a different type of challenge to the company. Apple is trying to scale its operations and supply chain model to meet much higher level of demand than it is used to.

The key lesson learned from this case is that optimizing one part of the value chain does not guaranty continued success and sustained competitive advantage in a rapidly changing market. Both Dell and Apple are trying to achieve excellence in the entire value chain instead of focusing on operations and distribution only (in the case of Dell) or product design only (in the case of Apple). Entire value chain excellence however does not mean total vertical integration.

4.3.3 Automotive Industry

The automotive industry presents a very interesting case from a benchmarking standpoint. While there are some key difference between the different automotive companies in their product development and sourcing strategies, the similarities in their approach to vertical integration and manufacturing processes is astonishing. Having studied some of the leading car manufacturers such as Toyota, General Motors, Nissan, and Chrysler, I realized that they follow very similar manufacturing processes from sheet metal stamping to spot welding to painting to final assembly. They also utilize a very high level of automation especially to perform stamping and welding operations in addition to their materials handling system.

Another key similarity is the level of vertical integration at a regional level. When Toyota decided to enter the US market, it established a US based design center in-house that utilizes some percentage of temporary workers and suppliers' engineering resources. Another objective of the regional design center is to provide a high level of customization in order to meet market specific requirements. This is a very similar approach to what General Motors or Chrysler would do. Toyota also established several vertically integrated manufacturing plants along with a network of dealers and service centers. Car manufacturers seem to adopt similar models when they expand into developing countries such as China or India. They follow a joint venture model with a local company with manufacturing capabilities and established distribution network.

Over the years, car manufacturers have outsourced some of the components and sub-assemblies such as electronics systems and seats to suppliers. However, they maintain a stronghold on certain aspects of the design such as engines, prototyping, and testing which they view as core competency. Even as competitors, car manufacturers tend to collaborate and establish partnerships in order to split the high cost of R&D for new technologies such as hybrid or electrical vehicles.

As I mentioned earlier, there are key differences between car manufacturers. The major differences are observed between companies that produce high volume of vehicles such as Toyota and General Motors and companies that produce low volume such as Porsche. Toyota for example spends 3.79% of its revenue on R&D compared to 9.82% in the case of Porsche which relies less on automation and more on manual processes that require craftsmanship.

Another key difference is the nature of the relationships with suppliers. General Motors for example either designs its components in-house or outsources them to suppliers with whom it has arms – length relationship. This forces the relationship to be more transactional and cost-focused. Toyota on the other tends to design fewer components in-house and outsource the majority of its components to suppliers with whom it has true partnerships (including minority holding position in these suppliers). The relationships with suppliers, which in most cases are co-located on the same campus or in the same city, tend to be long term and based on mutual trust and benefit.

% of Total Component Costs	Internally Manufactured	Partner Suppliers	Arm's-length Suppliers
Toyota	27%	48%	25%
General Motors	55%	10%	35%

Table 2: Profile of Toyota's and General Motor's Suppliers (Dyer J. H., 2000)

The main lessons learned from the automotive industry which follows a high level of vertical integration at a regional level are:

- Manage customization at a local level through a series of de-centralized regional design centers and adopt the highest levels of standards for emission, safety, and chemical use
- Standardize units of measure and design package format when sharing design responsibility across multiple regions
- Establish long-term partnerships with suppliers based on trust, collaboration, and mutual benefit
- Understand the key drivers behind selecting a regional versus centralized strategy. In the case of the automotive industry, some of these factors are:
    - Country requirements to do business
    - Currency exchange rate
    - Import / Export balance ratio
    - Image of national pride (domestic versus foreign car)

4.3.4 Aerospace Industry

The benchmarking study for the aerospace industry focused on comparing two programs within the same company, Boeing. The two programs were the **737** (the more traditional and most successful program in Boeing's history) and the **787** or **Dreamliner** (Boeing's latest program which is still under development). Historically, Boeing followed a product development model where most of the design work was done in-house. Some fabrication was done in-house and the rest was outsourced to suppliers who were located in the US (some co-located with Boeing in the Seattle area). Boeing maintained full control over system integration (final assembly) and testing. The 737 program followed a similar product development strategy.

With the 787 program, Boeing ventured to try out a fundamentally different product development model. Boeing decided to define the high level design specification for the new aircraft such as material (carbon-fiber or composite), footprint, geometry, weight, and load requirements; then to outsource the detailed design and fabrication of the sub-assemblies to global distributed suppliers in Japan, Italy, France, China, the UK, and the US. When all sub-assemblies arrive together at Boeing's Everett, Washington facility (most of them via retrofitted 747 planes named Dreamlifters), Boeing takes the responsibility of performing final assembly and test. This is consistent with Boeing's stated corporate vision of being a "large scale system integrator" (Griffin, 2006) which is also viewed by most as Boeing's core competency.

The rationale behind Boeing's decision to outsource design was to share the risk and capital investment of developing a new program which was estimated to exceed $10B (Johnson & Greising, 2007). In addition, outsourcing work to suppliers in strategic global markets provides Boeing with access to customers as well as talent pools in these markets. As of this date, Boeing has experienced several setbacks that resulted in the delaying the release of the first 787 by two years. It is too early to tell whether Boeing made the right decision to outsource such an important portion of its core business (including wing design) and whether Boeing made the right sourcing decisions. There are efforts underway to analyze the 787 product development model and recommend a better model to be used for future Boeing programs.

Key lessons learned from benchmarking Boeing's 737 and 787 programs include:

- Do not underestimate the complexity and cost of outsourcing design and manufacturing of complex systems to globally distributed suppliers in an environment where engineering design changes are very frequent, logistics and inventory holding costs are high, and labor relations are tense
- The simultaneous development of new technology (carbon-fiber design and fabrication) and new products (787) is too risky
- Outsourcing technology can lead to loss of intellectual property (IP) and creation of future competitors

4.3.5 Heavy Industry

Two companies from the Heavy Industry with products similar in scope, complexity, and volumes to FMC were selected. These companies were Caterpillar and ABB. Caterpillar is the world's largest maker of construction and mining equipment, diesel and natural gas engines, and industrial gas turbines. ABB is a global leader in power and automation technologies that enable utility and industry customers to improve their performance while lowering environmental impact.

Caterpillar utilizes a centralized vertically integrated product development process. Detailed product design is done in-house using standardized processes and limited product customization. Prototypes are also developed and tested in-house using the same suppliers, materials, and processes that will be used in real production as a proof of concept. Fabrication and system integration are also done in-house. In order to ensure continuity and accountability throughout the project, both design engineers and sustaining engineers report to the same engineering manager. Engineering resources are rotated between the two groups to ensure knowledge transfer. There is a program management office staffed with professional project managers with responsibility to lead projects by managing capital budgets, resources, and schedules.

ABB uses a joint product development approach with its suppliers. Some design work is done in-house in local design centers and the rest is outsourced to local suppliers. The ownership of IP is shared between ABB and its local suppliers. Prototypes are developed and tested in-house in fragmented local centers and fabrication follows a mixed model between in-house and outsourced. System integration and testing is done in-house and at customers' sites.

The key lesson learned from analyzing this industry is the importance of capturing and transferring implicit knowledge throughout the entire product development process. Tacit knowledge can be used as a competitive advantage and it is proportional to the amount of development work being done in-house.

4.4 Key Learning

Other general learning from this benchmarking study includes:

- Understanding own core competency, competitive advantage, and brand image is crucial to the success of any business
- The level of vertical integration of any given company and the strategic sourcing decisions that it makes can vary between different product line and different markets.
- Outsourcing design, prototyping, fabrication, system integration, or testing will result in loss of implicit knowledge and can lead to loss of IP
- It is relatively easy to quantify the benefits of outsourcing based on labor savings or tax incentives. However, it is important to capture the true cost of outsourcing which may include loss of product expertise, higher total cost of ownership and potential creation of future competition

4.5 Conclusions

In conclusion, it is evident by analyzing different world class companies from different industries that there is not one correct answer when it comes to determining product development strategy. However, there is evidence that focusing on core competency and maintaining key differentiators (products, functionalities, or services) in-house can provide companies with competitive edge. It is also improtant to align the product development strategy with the company's overall corporate strategy.

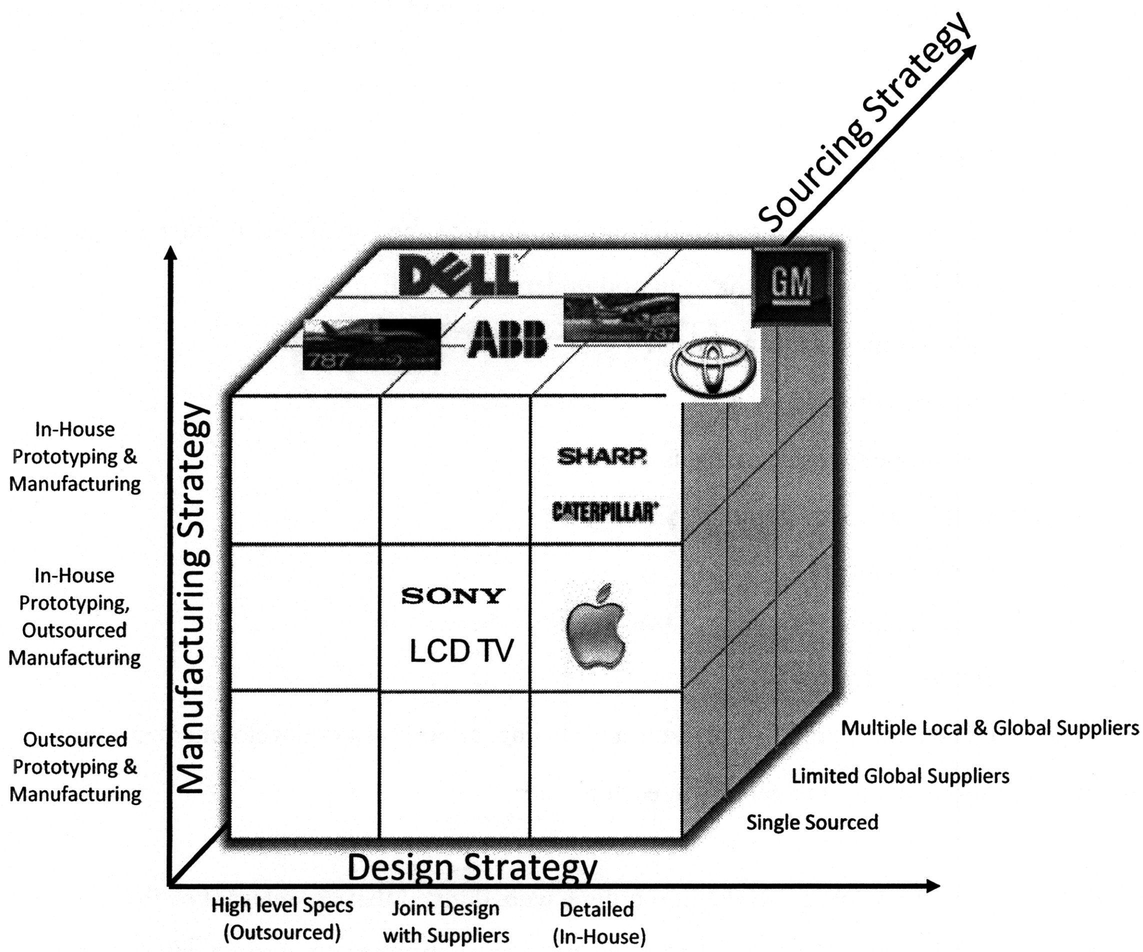

Figure 5: Three Dimensional Representation of Benchmarking Results

5 Methodology

In this chapter, I will present a general framework that FSG can utilize in order to select the most appropriate development strategy at a product level, technology level, or functionality level. The framework is based on key learning and observations that resulted from the benchmarking study presented in Chapter 4 and from analyzing current and past product development projects at FSG.

5.1 Evaluation Criteria

By studying world class companies and understanding some of the key drivers to their success, it is apparent that all of these companies have a good understanding of:

- What their customers value and need
- What their core competency is
- What their competitive advantage is
- What their Product Development Strategy is
    - Design Strategy
    - Manufacturing Strategy
    - Sourcing strategy
- The dynamic nature of global markets and its impact on product development strategy
- The requirements to do business in each country

Using the above observations, six evaluation criteria were derived that are relevant to the development of T&E units. As part of determining the most appropriate product development strategy, each product functionality and product feature should be evaluated against each of the six criteria. Based on the outcome of answering a list of six questions (one for each criterion), a development strategy is recommended for each product functionality or feature. The six criteria used for evaluation are:

1. **Differentiation:**
   From the perspective of the end customer, does the functionality or feature differentiate FMC from its competitors?

2. **Operational Efficiency:**

   Does the functionality or feature provide FMC Field Operations with operational efficiency benefits such as safety, reliability, or lower operating expenses that could enhance overall competitive advantage?

3. **Design Expertise:**

   Does FSG have in-house design expertise capable of designing the particular product functionality or feature? Expertise in general has two components to it: Formal educational background and training, and previous work experience.

4. **Manufacturing Expertise:**

   Does FSG have in-house manufacturing expertise capable of doing design for manufacturability, defining assembly sequence, and implementing lean manufacturing methodology?

5. **Regulations:**

   Are the products being designed subject to regulations such as ATEX, CE Marking, DOT emissions and weight limits?

6. **Level of Customization:**

   Is the product being developed considered a commodity or is it highly customizable by region or by customer?

5.2 Decision Making Tool

Applying the decision making tool described in Figure 6 below allows FSG to make product development strategy decision on a case by case basis instead of using the current model of in-house design, outsourced prototyping, test, and manufacturing.

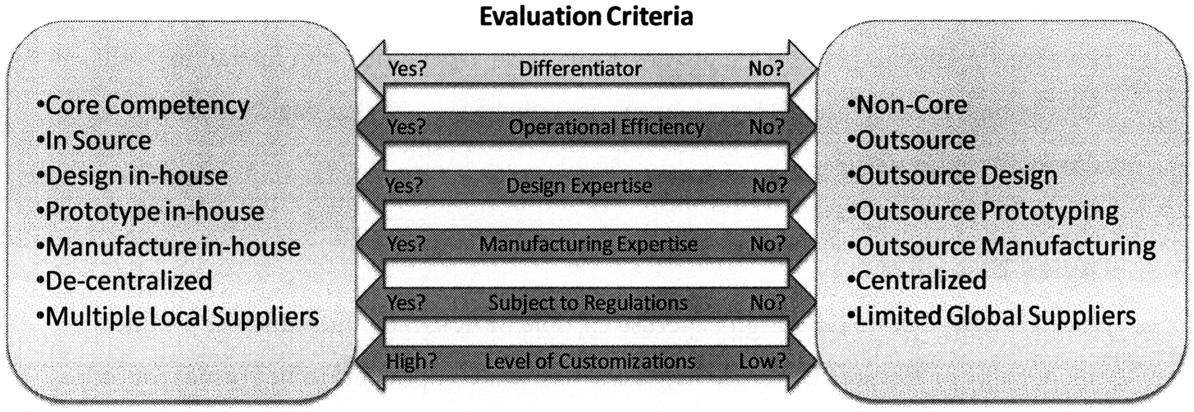

Figure 6: Evaluation Criteria

The rationale behind making these decisions is that functionalities and features that are either viewed by customers as differentiators or provide FMC with substantial operational advantage (or both) should be maintained in-house and considered core competency. The level of vertical integration depends on the current level of expertise within the organization and commitment to further develop expertise in the future.

As far as strategic sourcing decisions, they are highly influenced by the level of vertical integration as well as regulations and level of customization. The more regulated the product is and the higher the level of customization is, the higher the need is for de-centralized design centers with local subject matter experts in regulations and customer specific needs.

5.3 Functionalities & Features by Product Line

Table 3 lists the main functionalities and product features that are currently utilized on each of the two T&E product lines (Cement Fluid Management, and Mobile Pumping). Each product line is also divided into Float (for onshore services) and Skid (for offshore services).

	Cement Fluid Management Float	Cement Fluid Management Skid	Mobile Pumping Float	Mobile Pumping Skid
Functionality				
Pumping	Yes	Yes	Yes	Yes
Blending / Mixing	Yes	Yes	No	No
Injection	No	No	Yes	Yes
Blow Out Prevention	No	No	Yes	Yes
Drum Reel System / Tubing	No	No	Yes	Yes
Power Generation	Yes	Yes	Yes	Yes
Transmission	Yes	Yes	Yes	Yes
Radiation	Yes	Yes	Yes	Yes
Software	Yes	Yes	Yes	Yes
Controls System	Yes	Yes	Yes	Yes
Storage	Yes	No	Yes	No
Transportation	Yes	No	Yes	No
Feature				
Safety	Yes	Yes	Yes	Yes
Modularity	Yes	Yes	Yes	Yes
Real Time Measurement	No	No	Yes	Yes
Footprint / Layout	No	Yes	No	Yes
System Integration	Yes	Yes	Yes	Yes

Table 3: List of Functionalities and Features by Product Line

6 Future State

The goal of this chapter is to apply the framework introduced in the previous chapter to each functionality and feature of two main T&E product lines: Cement units, and Mobile Pumping units.

6.1 Applying the Framework

Table 4 below applies the evaluation criteria to each functionality and feature of T&E products.

	Competitive Differentiator	Operational Efficiency	Design Expertise	Manufacturing Expertise	Subject to Regulations	Level of Customization
Functionality						
Pumping	Yes	Yes	Yes	No	No	Medium
Blending / Mixing	Yes	Yes	Yes	No	No	High
Injection	Yes	Yes	No	No	No	Medium
Blow Out Prevention	No	No	No	No	Yes	Low
Drum Reel System / Tubing	No	Yes	No	No	No	Medium
Power Generation	No	No	No	No	Yes	No
Transmission	No	No	No	No	No	No
Radiation	No	No	No	No	No	No
Software	No	Yes	Yes	N/A	No	High
Controls System	No	Yes	Yes	No	No	High
Storage	No	No	Yes	No	Yes	Low
Transportation	No	No	No	No	Yes	Medium
Feature						
Safety	No	Yes	Yes	No	Yes	Medium
Modularity	Yes	Yes	Yes	No	No	N/A
Real Time Measurement	Yes	Yes	Yes	Yes	No	High
Footprint / Layout	Yes	Yes	Yes	No	No	High
System Integration	No	Yes	Yes	No	Yes	High

Table 4: Evaluation Criteria and Decision Making Tool

6.2 Results

Based on the answers obtained from the evaluation matrix above, the recommended strategy for each functionality and product feature is listed in Table 5 below. The overall strategy is also summarized in Figure 7 on the same three dimensions previously used for the benchmarking study.

	Design Strategy	Manufacturing Strategy (Prototype)	Manufacturing Strategy (Production)	Sourcing Strategy
Functionality				
Pumping	In-House	In-House	Outsource	Global
Blending / Mixing	In-House	In-House	Outsource	Global
Injection	Joint	Outsource	Outsource	Global
Blow Out Prevention	Outsource	Outsource	Outsource	Local
Drum Reel System / Tubing	Outsource	Outsource	Outsource	Global
Power Generation	Outsource	Outsource	Outsource	Global
Transmission	Outsource	Outsource	Outsource	Global
Radiation	Outsource	Outsource	Outsource	Global
Software	In-House	N/A	N/A	N/A
Controls System	In-House	Outsource	Outsource	Global
Storage	Outsource	Outsource	Outsource	Local
Transportation	Outsource	Outsource	Outsource	Local
Feature				
Safety	In-House	N/A	N/A	N/A
Modularity	In-House	N/A	N/A	N/A
Real Time Measurement	In-House	In-House	In-House	Global
Footprint / Layout	In-House	In-House	Outsource	Local
System Integration	In-House	In-House	Outsource	Local

Invest
Divest

Table 5: Summary of Recommendations

6.3 Design Strategy

Based on the results presented in Table 5 above, it is apparent that customers consider Pumping and Blending functionalities to be key differentiators. Currently FSG performs detailed design work on blending modules, while pumping modules design is handled on a case by case basis. FSG design engineers may choose to use a standard off the shelf pump or they may choose to design a new pump from scratch.

Another key functionality identified as a differentiator is Injection. Currently FSG outsources the design of its injector heads for Mobile Pumping units. However, since the requirements for injection technology are becoming more demanding and more complex, it is recommended that FSG invest in joint design development with its suppliers.

The other functionalities that are considered key differentiators are Software and Controls Systems. Currently FSG completes all of its software and controls systems design in-house by a centralized team of software and controls engineers that is shared between the different projects.

As far as product features, it is clear that maintaining in-house design capability and expertise is essential. Overall system integration, modularity, footprint, and safety are vital factor for selecting FMC products over its competitors both for offshore skids and onshore trucks. For example a modular, compact, and reliable cementing skid is very desirable in an offshore rig application.

6.4 Manufacturing Strategy

In the early 1990s, FMC re-evaluated its product development strategy and decided to adopt one strategy for all of its T&E units and that is to design in-house and outsource prototyping, testing, and manufacturing. Currently FSG does not have in-house system integration or manufacturing capability with the exception of few test and inspection bays on its main campus.

Given that prototyping and testing play an integral role in the product design process, and that capturing and transferring implicit knowledge acquired during the prototyping process is nearly impossible, it is recommended that FSG establish an in-house prototype shop to integrate and test its T&E products. The prototype shop could be used to assemble pumping and blending modules in addition to performing complete system integration and yard test.

Having the design engineers within a walking distance from the prototype shop allows them to rapidly pilot different ideas and concepts. They can also address design related issues and capture lessons learned much faster. Manufacturing engineers will also benefit from the physical proximity to the prototype shop by having more control over the production processes and assembly sequence. Sustaining engineers can also benefit from early engagement on projects during prototype phase and will be much more prepared to handle the products upon commercialization.

In order to minimize FSG's capital expenditure and risk, it is recommended to maintain an outsource model for manufacturing once the product has been commercialized. This strategy can be re-evaluated in the future on a product by product basis.

6.5 Supply Chain Strategy

Historically, FSG used to source its prototyping and production to local suppliers then export its final products to its geo markets. Recently, FSG started to use a local supplier for prototype and pilot builds and then select a different global supplier for production builds. This new model added a level of complexity due to the fact that assembly processes and lessons learned during prototype phase are not well documented and the design drawings are not always updated.

Based on the framework presented in this research study, it is recommended that the future state sourcing strategy for FSG T&E units should follow one of two models:

1. For functionalities and features that are highly sensitive to regulations and customization such as safety and system integration, FSG should partner with local suppliers to produce commercialized units. FSG should also deliver complete design packages and documented assembly instructions to its suppliers in order to standardize the manufacturing processes.

2. For functionalities that are not as sensitive to regulations and customization such as pumping and blending, FSG should partner with limited global suppliers for production and in some cases leverage suppliers' design capabilities to perform joint product development.

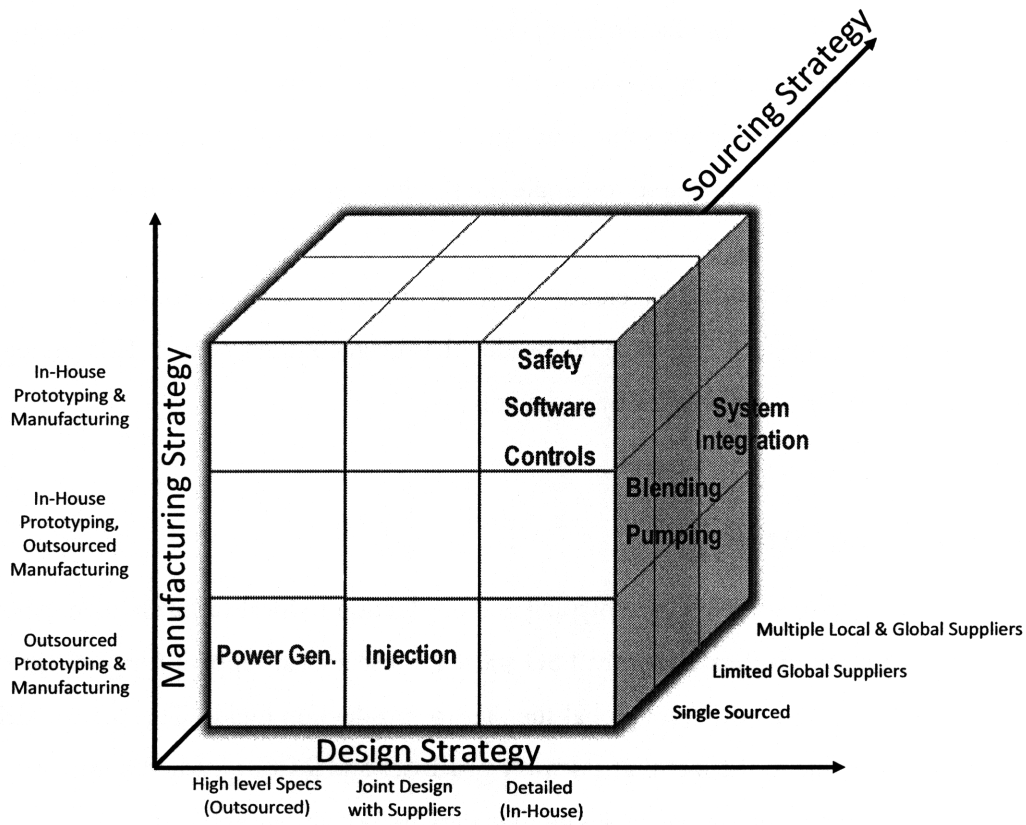

Figure 7: Summary of Overall Product Development Strategy Recommendations

7 Recommendations

In this chapter I will summarize the high level recommendations by group (Design Engineering, Manufacturing Engineering, and Supply Chain Management). I will also list some of the anticipated barriers to implementation. Finally, I will provide some direction for future research and next steps.

7.1 Design Engineering

- Align teams and build up expertise to focus on key functionalities (Blending, Pumping, Injection, Software, and Controls) and key features (Safety, Modularity, System Integration, and Footprint) as opposed to team structure based on product lines or specific projects
- Outsource the detailed design of Storage and Transport units to local suppliers and provide them with high level design specification
- Partner with a local supplier to jointly design and develop injector heads for Mobile Pumping units. Maintain at least joint ownership of Intellectual Property (IP)
- Standardize, document, and adhere to definitions of "detailed design package" including drawings, BOM, revision control, and Configuration Management (CM)
- Invest in in-house prototyping capability for blending and pumping functionalities and system integration in order to recapture implicit knowledge. The prototype shop should have full process and technical capability to assemble and test prototype units and pilot units
- Place an FMC Regulations expert in each of the different design centers to provide project teams with guidance on local regulations.

7.2 Manufacturing Engineering

- Build up manufacturing expertise around key functionalities by hiring process engineers with experience in Lean manufacturing, Six Sigma, and Design for Manufacturability concepts
- Early engagement by the manufacturing engineering team on new product development projects to be able to influence the design at an early stage of development

- Review and critique detailed design drawings to determine ease of manufacturing and assembly
- Define, document, and standardize detailed prototype system integration work instructions

7.3 Supply Chain Management

- Identify, qualify, and build long term relationships with local and global suppliers
- Ensure that sourcing decisions meet all requirements (financial, technical, quality, and strategic) by engaging a cross-functional team in the decision making process
- Minimize total inventory in the supply chain and share the benefits with suppliers
- Contractually protect intellectual property for projects with joint development
- Build up Supply Chain Management and Strategic Sourcing expertise and dedicate resources to create a long term supply chain strategy for the entire organization

7.4 Barriers to Implementation

While the recommended product development strategy was widely accepted in theory, it is important to point out some of the major barriers that would either prevent or slow down the actual implementation of the new strategy.

Implementing the new strategy requires capital investment in building and staffing a prototype shop as well as hiring and training additional engineering and supply chain resources. Given the current economic situation surrounding the Fluid Management industry in general, it will be an uphill battle trying to justify additional spend even if the business case is favorable from an economic perspective. Another risk factor is the need to potentially terminate existing relationships with traditional suppliers and establish new relationships based on business needs.

7.5 Next Steps

The recommendation is to implement the proposed strategy in a phased approach in order to prove the concept while minimizing risk and capital expenditure. Some of the next steps that I recommend following include:

1. Complete a detailed business case (cost/benefit analysis) for building a prototype shop on FMC main campus
2. Start with in-house system integration for blending and pumping modules first with the help of existing suppliers
3. Expand system integration to complete systems such as Cementing units or Mobile Pumping units
4. Start joint development of injector heads with a local supplier
5. Share knowledge and lessons learned with other FSG sites and other FMC groups.

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