A Case Study of a Product Architecture

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Abstract

The primary purpose of this thesis is to document the product design and development of the first product family at General-Electro Mechanical Corporation (GEMCOR), an automatic fastening producer for aerostructure assemblies. The thesis serves both as a case study for academics as well as a model by which the company should conduct further successful product developments. It is quite a remarkable and nontrivial occurrence in the history of the corporation that a product family should be created with extensibility, to encompass new technologies for competitive advantage in addition to covering the entire commercial airplane market automatic fastening requirements for the foreseeable next ten years. Heretofore, the products developed have appeared similar from a distance, but in fact they were not products; instead they were individual prototypes which had certain similarities. The study goes on to show how the world economic influences, competing technological trajectories, the customer supply chain, competition, and organization structure and policies shape the system architecture of the products developed in an extensible product family. This first product development described in this thesis is to serve as the model to follow for Gemcor's future product developments.

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[1] The author considers manufacturing as a subset of the enterprise system and therefore has preceded LFM with the SDM.

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Section 1

Introduction

This study provides a description of the factors leading to the development of a new product line and the design of an organizational structure to support this first of expected many product families. The intent is to apply the core competencies of our company toward sustaining corporate growth with a positive economic value added in perpetuity using product development as the fuel.

It can be an exciting and yet anxiety arousing experience for a company to give birth to a new product line. The economic and psychological pressures can be great hurdles in the path of any successful product development. The development described herein actually required a different paradigm and almost radical departure from the company's historical way of doing business and probably would not have happened without senior management leading the breakaway from the past. The difficulty of product development cannot be fully appreciated until one experiences the entire life stages from the creation of the idea through its market acceptance. In some cases members of the original team must be replaced once or twice until success is ultimately achieved. Often new products do not make it to the market because of a lack of perseverance by upper management, a lack of funding, or a reluctance by the marketplace to accept the new product idea. The inventors and patent holders sometimes do not receive the fruits of their ingenuity and labors, which instead are garnered by later management, but inventors often do not have the marketing personality or organizational wherewithal to bring their ideas to the market. It is well documented that organizations from modest to large size develop an inertia, a resistance to change, which stifles innovative thinking and risk-taking for the long-term survival corporation. New product development is a risky business. It is an adventure technically, socially, and economically for the corporation. Efforts in the wrong market direction or even wrong timing -- introducing a product prematurely, can have devastating and life-threatening effects on a corporation and its leaders, such as happened in the cases of Iridium and the Apple Newton.

Gemcor, General-Electro Mechanical Corporation, created the field of automatic fastening in commercial airframe structures, opening up as a design-manufacturing company in 1936. It took from the late 1940s until the 1970s for the market to recognize the full importance of this branch of assembly automation with respect to the quality improvement of airframe structures, coming in the form of increased fatigue life and joint strength as well as improved product throughput and cost savings. As customers abhor a single source of supply, or supply chain dependence, due to concerns about overpricing and lack of timely responsiveness from the supplier, customer induced competition eventually appeared. Gemcor's continued existence was threatened by a combination of regional competition and a new technology which might substitute for the company's hydraulic, servo based, automatic fastening systems. As a consequence, Gemcor's development efforts worked for two years on alternative electromagnetic riveting systems without any real product breakthrough. Then following a serendipitous discussion session, a superior solution was conceived but in the form of an all electric system to serve as the base technology upon which to build a modular, significantly lower cost, and flexible product line.

This thesis describes where the company was before this technological groundbreaking, the key technological factors influencing the product development, market factors, the competition, the functionality and architecture of the automatic fastening system, the new organizational structure required, and core competencies needed for now and the future.

Many companies do not have the capital resources to simultaneously pursue different product family developments. The time-to-market and investment payback period is normally several years. An alternative approach was studied using system dynamics modeling to derive a system behavior for identifying market opportunities in the same, similar or different market segments based on the core competencies of a corporation in developing new products. Using this model, a paradigm was created for product development and product portfolio expansion requiring modest initial capital funding while mitigating risk.

Section 2

A Business Description of Gemcor

History
Gemcor was incorporated in 1936 as a design and welding company particularly catering to the airframe production market which was mostly located at that time in Buffalo, New York. During WWII riveting was manually done worldwide – Rosie the riveter. In Buffalo, NY, where considerable fighter and bomber aircraft production took place, Gemcor developed gang squeezers which clamped, pressed, and squeezed simultaneously several rivets in panels to save time. In 1948 the Drivmatic® process was invented and developed by Gemcor.

The Drivmatic® automatic riveting process substantially improved quality, fatigue life and joint strength of airframes. It created a niche market by providing automatic fastening machines and associated automatic part and machine positioning systems. This process has gone through technical evolution in speed and precision. The design of commercial aircraft today is wholly dependent on this automation process, which has resulted in substantially reduced aircraft weight and cost. The most important improvement in these affected airframe designs has been the wing structure due to a novel Gemcor fastener design complemented by a required automated installation process. Today Gemcor has over 70% market share worldwide in this niche market and has just introduced a new, all electric, modular product line which can be configured to suit the customer's wants. This new product is more robust, easier to operate and maintain, lower cost, and much quicker to produce.[2]

A holding company, Gemcor Systems Corporation (GSC), was formed to diversify the company. In addition to this first product development, it created the now highly profitable Gemcor Service Support Technologies (GSST), which is intended to be a growth business in service support of Gemcor's already installed product base, for installations of new Gemcor products, and for provision of spare parts. GSST is also chartered to develop its own core competencies and diversify its growth based on these competencies.

The company's size depends on backlog and in 1998 was 250 employees with annual sales of $35 million with a production rate of fifteen systems per year excluding the spare parts and service business. In 1998 after considerable internal and external discussions concerning the soul searching subject of who we are as a company and organization of people, review of the work we have accomplished in the past, and profoundly what is our purpose and mission, we have chosen the multifaceted global industry of automatic assembly. (See heading "Assembly Automation: Industries Future Market Segment Potential" further on.) The summary of this investigation is provided below.

Gemcor's mission = vision is:
To be the best in the world in aerostructure assembly automation, providing value to our customers. Execute this with excellence in customer satisfaction plus one, providing opportunities for growth and security to all our stakeholders.

[2] Gemcor was also ISO 9001 quality certified in 1994.

Corporate Financial Objectives
Highly positive economic value added (+EVA) with a cost of capital hurdle rate of 15%, highly positive revenue growth, and highly positive net cash flow.

<u>Gemcor's Current Core Competencies</u>
A company successfully evolves by basing its activities on its core competencies and technologies which constitute competitive superiority.[3] The following list identifies Gemcor's primary skill assets.

- Motion Controls (application)
- Valves
- Motors
- Actuators
- Position Feedback Devices
- Computer Controls
- Data Bus Systems
- Operating Software
- Drivers
- Human Machine Interface (HMI's)
- Displays
- Mechanical Application of Motion Controls
- Fastening Process Development
  - Servo positioning and upset technology
- Metal Forming
  - Aluminum
  - Titanium
  - Fastener forming
  - Fastener installation
  - Processes
    - Cold forming
      - Squeezing
    - Roll forming
    - Metal spinning
    - Press brake forming
    - CNC punch press
    - Laser cutting
    - Welding
- Fastening of Wing and Fuselage Assembly
- Ability to Consistently Provide Customers with Value
  - Provide solutions for automatic riveting applications
    - Airframe structural design for automatic fastening
      - Airframe structural design
        - Joint design
          - Type of joint
            - Type of fastener
              - Type of installation process
    - DFMA for our customers

[3] <u>Competing for the Future</u>, G. Hamel and C. Prahalad, Harvard Business School Press, 1994.

        - Agile part fixturing
        - Factory Layout for ROI
    - Systems design and integration
        - Differing systems made by Gemcor and others brought together into a single working mechanism, which provides value to the customer
- Prototyping Ability (precursor to Product Development)
    - Fast Time-to-Market (TTM) for new products/ services
        - Ability to bring new and practical technologies to market quickly
            - Systems integration
                - Technologies integration
- Machine Tool Design and Build
        - Hydraulics and electrical integration
- Decision Making Competence
    - Negotiating
    - Choosing the best course of action
- Learning Organization
    - Measurement-compulsive to make processes better (Fast and Accurate Information Feedback Loops)
    - Project management
    - Fast TTM order fulfillment
    - Intellectual knowledge leadership in joining technologies
        - Ability to protect and exploit our intellectual rights
- Information Technology
    - E-commerce, supply-chain management

Strategy Development for Future Direction

The organization is like an individual. It has a current skill and knowledge set which must be assessed against future market demands to determine if the skill set needs to change for future survival and/ or for achieving self-actualization. Technology based companies[4] possess a skill and knowledge set in the form of core competencies, complementary assets and core technologies. This talent set will need to evolve or change over time as the market place (the environment) changes. The broad global field of assembly automation seemed to be apropos since automatic assembly of aerostructures is a subset of this industry. This market can be segmented as shown in the list below.

Assembly Automation: Industries Served (Future Market Segment Potential)

- Aerospace
- Appliance
- Automotive and Components
- Computer
- Electronics
- Food Processing
- Furniture
- Medical Devices
- Consumer Disposable Products

[4] Most companies today are influenced by technology and must revamp themselves to develop competitive advantages by the use of technologies (i.e., Information technology, e-commerce and its related electronic supply-chain management).

- Packaging
- Pharmaceuticals
- Telecommunications

Complementary Assets

- Installed Machinery and Systems Asset Base (>95% of Automatic Fastening Machines used for Aerostructural Assembly Worldwide)
- Customer Network and Established Relationships in Commercial Aerostructural Assembly Market Segment
- Strong Brand Name in the Aerostructural Assembly Market Segment
- Patent Rights
- Pacific Aerospace and Electronics (Fixture Systems Supplier Alliance Partner)
- Winsmith Gear Boxes (Gemcor owns design rights)
- PROCTECH(Motion Controls partner in Germany)
- Sales Agents
    - France, Germany, Italy, Japan, China, Spain

Core Technologies (Knowledge in Which Gemcor Must Always Stay Current)

- Fastener Design
- Drilling
- Fastener feeding
- Motion controls
- Sensors
- Software
    - Networking
    - Human Machine Interface (HMI)
        - Process control
        - Operator
        - Maintenance
- Machine and component control
- Joining automation technologies
- Fastening process knowledge
- Assembly automation knowledge
- Fixturing knowledge
- Aerostructural design
- Composites
- Simulation by design (CAD/ CAM/CAE)
- E-commerce, supply-chain management
- Metal forming
- Aluminum
- Titanium
- Fastener forming
- Fastener installation processes
- Processes:
- Roll forming
- Cold forming
- Squeezing

- Metal spinning
- Press brake forming
- CNC punch press
- Laser cutting
- Welding

This section focused briefly on the history of Gemcor in the automatic fastening field of aerostructure assembly. For organizational and business diversification the company developed a mission and vision statement, core competencies and core technologies description and have pursued their application to the diversely global assembly automation industry.

Section 3

Technological Factors Affecting the Strategy for Gemcor

Technological change is constantly occurring, some of it complementary to the present architectures of a company and some change a substituting threats. Both types need to be tracked by a company to ensure survival in a competitive environment. This section studies both types of technological changes occurring in the commercial aerostructure automatic assembly niche with respect to the possible effects on Gemcor. For example, technological changes are currently taking place in airframe structural design. New joining processes are being developed, based upon those aerostructural material substitution and parts fabrication methodology changes anticipated in future aircraft design and manufacturing. Gemcor must determine its technology strategies by which to survive and thrive in the market of the future through its customer-centric, value-added contributions to aerostructure design manufacturing and assembly automation. As can be seen in Figure 3.1, Gemcor is currently in the mechanical fastening specialization and has potential technological growth opportunities in the categories of heat fusion and chemical bonding, described further on.

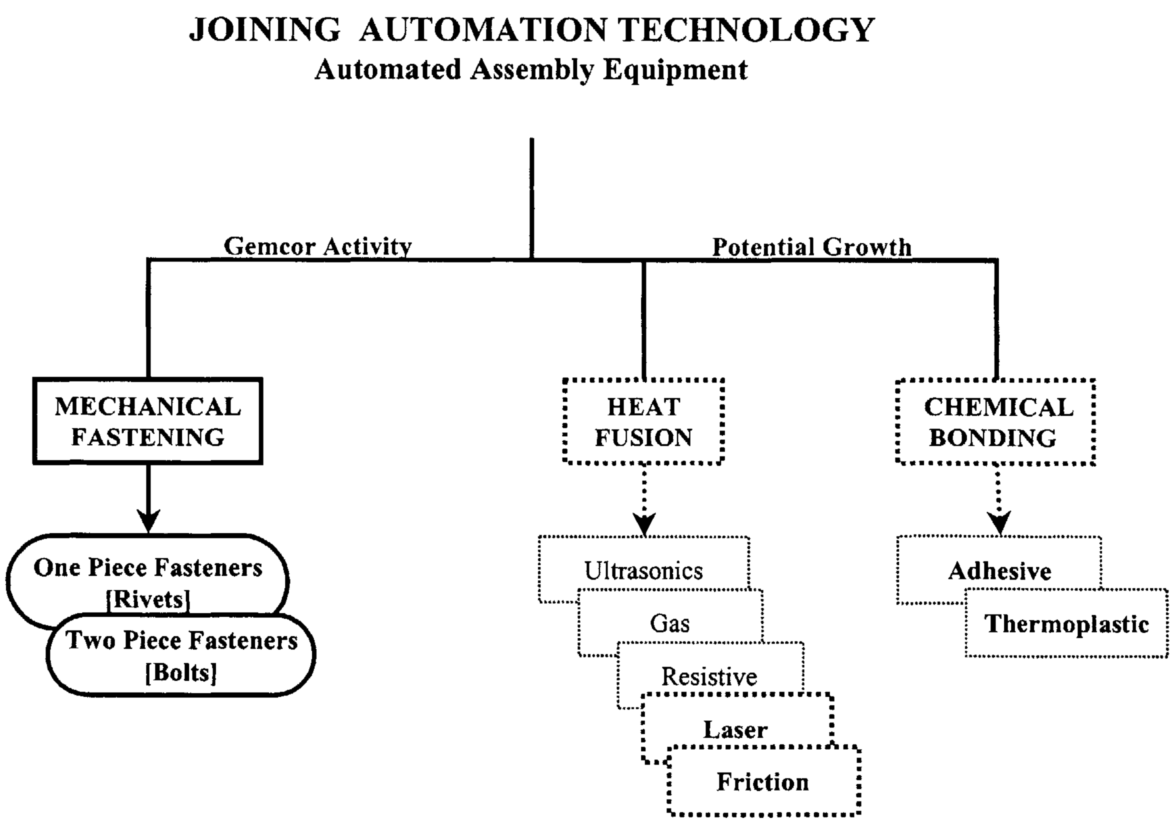

Figure 3.1 Joining Automation Technology

Safety and Efficiency

The traditional drivers to aircraft design are safety and efficiency. Safety translates to structural strength, fatigue life, functional reliability, and extremely low probability of catastrophic failure. Aircraft efficiency relates to cost of operation, which is dependent upon operating costs (crew personnel and fuel) and maintenance costs. Fuel cost is reduced by lighter aircraft and reduced surface drag. Gemcor sees itself as a major contributor to safety by producing aerostructures with higher fatigue life and joint strength.

Design for Manufacturing and Assembly (DFMA)

DFMA was made a tactical practice by manufacturability metrics developed by Boothroyd and Dewhurst.[5] DFMA, as a philosophy more so than exactly which technique is used in its application, is having an ever growing influence in shortening or making concurrent the connection of design and build, which is accentuated by the increasing prevalence and power of software simulation and solid modeling CAD/CAE/CAM[6] tools and cross functional team organizational processes. In addition, the sensitivity to and understanding of organizational system processes are influencing how product designs should not only function but how they should be cost effectively produced. A significant emphasis in DFMA is the reduction of parts and fasteners. Generally, fasteners are considered time-consuming in the manufacturing process and not easily automatable. The consideration of consolidating many parts into a single or very few parts along with snap together techniques for assembly is being heavily emphasized now in engineering schools throughout the world. This fewer parts trend is extremely important to cost reduction and improved product robustness by complexity reduction. DFMA emphasis must be taken into account when considering the future of aircraft design. The closer the part that automation providers can play in the design process, the better the results will be for design and build system solutions. DFMA will open new opportunities for automation in manufacturing and assembly that could not easily exist before because of chimney organizations of departmentalism and corporate bureaucracies. Gemcor engineering and key production personnel received training in DFMA and are actively using solid model CAD/CAE/Simulation/CAM design software tools. The philosophy is to simplify designs with fewer parts and easier manufacturability.

High Velocity Machining

Related to DFMA is high velocity machining (HVM), which is being considered as a substitute for the assembly process. HVM uses rapid, shallow cutting passes to keep heat in discarded chips and prevent transfer of heat warping the part. The automated process reduces component weight, manufacturing time, inventory, and tooling costs. Use of monolithic aluminum structures eliminates riveting created part growth, multiple drawings, shimming, and labor required to fabricate complex parts. The company Remmele builds in-spar ribs for commercial jets using eight automated Forest-Line 5-axis mills with 40,000 rpm spindles and linear cutting speeds of up to 800 inches/min. Remmele is investigating the use of an automated laser welding process to join and seal thin wall aluminum structures made using HVM. They are also looking at adapting HVM for titanium.

CAD/CAM and high-speed machining of components from monolithic aluminum billets were first heavily utilized for commercial aircraft fabrication by Airbus on its original aircraft designs. Even MBB[7] was much more advanced than Boeing in its early usage of CAD/CAM, which it developed for the military Tornado aircraft titanium parts fabrication. A difficulty that Airbus encountered was structural cracking at stress rising points. Design improvements to reduce stress risers have significantly diminished the cracking problem. In recent years Boeing has finally caught on to the cost effective

[5] Product Design for Manufacture and Assembly, G. Boothroyd, W. A. Knight Peter Dewhurst, Marcel Dekker publisher, 1994.

[6] Computer automated design (CAD), computer automated engineering (CAE), computer automated manufacturing (CAM)

[7] Messerschmitt-Bolkow-Blohm

technique of reducing numbers of parts, and it is now actively pursuing sculpturing of parts from aluminum and titanium monolithic billets.

When Airbus first started designing machine sculptured parts in the late 1970's, a shock wave went through Gemcor. Fewer fasteners meant a reduction in automatic fastening systems. At that time some designers at Boeing maintained that the Airbus structures were more vulnerable to stress risers and cracking leading ultimately to structural failures. Also, Boeing believed that fatigue life was longer with multipart structures which were strong and flexible compared to rigid sculptured parts. Twenty years later there is still no clear winner of the debate, and many fasteners are still being used by both aircraft producers.

Materials Influencing Future Design and Build of Commercial Aircraft

There is a competition among a combination of materials along with their associated build practices for designers' selection with respect to future aircraft over the next ten years and for aircraft farther out in time. The competition is among aluminum alloys (traditionally used in aircraft), aluminum-lithium alloys, titanium alloys, composites (thermoset and thermoplastic), active metals, and high-speed machining of parts from monolithic aluminum and blocks.

Aluminum Alloys

Aluminum has been traditionally used in aircraft for its lightness, strength, high fatigue life, corrosion resistance, nonmagnetic properties, ease of manufacture, parts machining, forming, and assembly. Over 90 percent of materials used in commercial aircraft are still made of various aluminum alloys. However, this material has an interesting difference compared to steel in that the welded joint of aluminum is weaker than its surrounding material. As a result, welding cannot be used for aluminum assembly of aircraft. Much of the early research on structural integrity of panels for alloys and joints was conducted during World War II and in the 1950s. There was considerable evidence for analysis from structural failures, which facilitated the learning process of proper structural design. The confidence in the continued use of aluminum is good for the sales of Gemcor's automatic fastening systems as a proven joining process for aluminum structures.

Aluminum-Lithium Alloy

The aluminum-lithium alloy is a lighter weight, stronger, and more brittle material than aluminum but is more costly as a result of its difficulty of manufacture. It was first used to produce floors for the C17, but cracking occurrences required aluminum material to be substituted back into the structure. It is now being seriously considered for the external tank of the space shuttle. Rather than riveting, Lockheed has decided upon friction stir welding as the joining process for the new Al-Li external tank. The AL-Li usage is very limited and can only serve as a potential opportunity for Gemcor to apply its technology or develop friction stir welding expertise.

Development of GLARE™, Glass Fiber Metal Laminates[8]

Fiber metal laminates (FML) were developed at Delft University starting over 20 years ago and have evolved into a family of hybrid, bonded fiber metal sheets and fiber/adhesive layers. (See Figure 3.2) This hybrid material is intended to provide a combination of the benefits of aluminum sheets and composites while simultaneously eliminating or significantly reducing their disadvantages. In particular, this laminated material provides excellent fatigue, impact damage tolerance characteristics, combined with a low density. FML also provides high burn-through resistance, as well as good damping and

[8] "Towards Application of Fiber Metal Laminates in Large Aircraft", A. Volt, L. Vogelesang, T. de Vries, Delft University of Technology, Faculty of Aerospace Engineering, 1999. Per this paper the material has been certified for airworthiness.

insulation properties. This material offers a 20 percent weight reduction compared to aluminum sheets. Fiber metal laminates are a "strong candidate material for especially large fuselage skin structures of the new generation of high capacity aircraft."[9] Delft University has traditionally had close ties with the neighboring company Fokker, which has excelled in composite structures for aircraft. Delft is also closely associated with Airbus Industrie's Deutsche Airbus in Germany, Aerospatiale in France, and British Aerospace in the United Kingdom. Airbus and the European Union may consider the GLARE material for its indigenously produced aircraft, and in particular the A3XX, to play a part in reducing operating costs by at least 15 percent below the B747-400. On the A3XX, the entire top half of fuselage around the passenger cabin is foreseen as a possible application for GLARE, in addition to other possible potential sites, such as cargo floors and liners, bulkheads, and flat skins.

FML shows excellent fatigue resistance and long cycle life compared to the typical aluminum sheets and structural techniques used in current aircraft design. Even when the aluminum layer cracks, the structure does not significantly lose its fatigue life. (See Figure 3.3) The aluminum shows resistance to impacts and lightning strikes. Cracks are usually easy to visually inspect as well as detect by use of eddy current and ultrasonic non-destructive crack testing. Crack stoppers and doublers are not as necessary to use for safety with these FML panels. GLARE has been successfully tested on the A330/340 fuselage barrel, a bonded patch repair installed on the C5A, a bulk cargo floor of the B777 of Boeing, and the bulkhead of the Bombardier Learjet 125. Repair of the GLARE panels uses standard patching methods with FML.

Large panels can be fabricated without the usual number of joints and rivets using a splice concept with overlapping aluminum sheets. These overlapped joined panels are put in a mold and then cured in an autoclave. The size of panels produced by this method is restricted only by the size of the autoclave. In the A330/340 fuselage panel successfully tested, no crack stoppers and doublers at the cracked joints were used.[10] It is claimed that this FML technology could serve as a breakthrough to significantly reduce the operating costs of the A3XX airplane due to its light weight, ease of maintenance, and product life extension, and potentially to reduce the price of airplanes as result of the production efficiency of joining this material. Delft University declares GLARE a "technology mature" fiber metal laminates variant. They assert that for aircraft the glass fiber metal laminate has excellent material properties; "furthermore, the splicing concept offers the possibility to increase the size of Fiber Metal Laminates without decreasing the excellent residual strength and fatigue properties. Integration of aircraft production steps in the production of Fiber Metal Laminates in combination with the application of the splicing concept yields a cheaper aircraft (in terms of production, operating and maintenance cost) at an increased safety level: damage tolerance is built in the material and GLARE has a high burn-through resistance."[11] GLARE is now a product of Structural Laminates Industries (SLI).

It is unclear if Airbus or other aircraft manufactures will adopt GLARE. This material can be easily automatically riveted but will reduce the number of rivets required and consequently reduce the number of automatic riveters in the assembly process.

[9] Ibid., page 1.
[10] Ibid., page 13.
[11] Ibid., page 17.

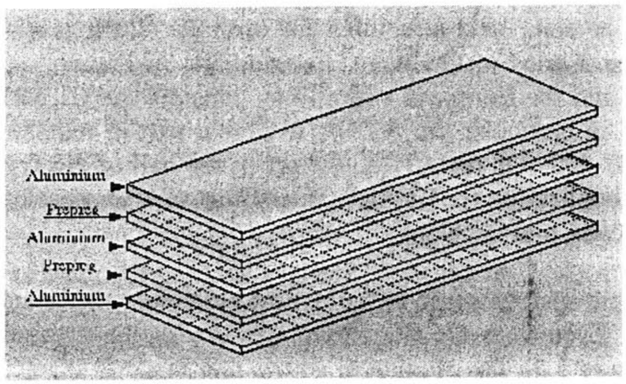

Figure 3.2
FML Laminations

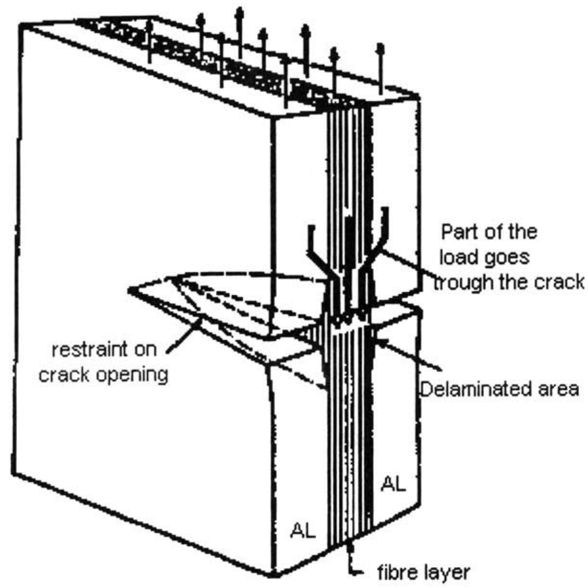

Figure 3.3
FML Crack Stopping Characteristic

Titanium Alloys
Titanium alloys are very lightweight and much stronger than aluminum but are very hard and brittle, which makes machining and forming costly and difficult. This alloy is used for the high strength load bearing requirements of the airframe structure in commercial aircraft. Due to titanium's galvanic compatibility with aluminum, there is little corrosion induced by their close proximity. Titanium fasteners, in addition to structural members, are commonly used in high stress load zones. Titanium had been very costly because of its scarcity. The opening of the Russian economy to the world market has increased availability of titanium so prices have been reduced. The use of titanium is prevalent in military aircraft, which experience much greater loads in their flight profile than commercial aircraft. Titanium is also quite heat resistant. Together with composites, titanium is commonly used as the inner frame structure upon which composite panels are fastened. Ti materials are commonly used in the joining process along with automatic fastening systems.

Composites
Plastic composites are made up of three basic components: resin, reinforcement fiber, and the lattice geometrical design. There are two different fundamental composite processes: thermoset and thermoplastic. Thermoset composites after lay-up are put into an autoclave and heated under pressure. Once set, there is no further movement possible in the composite. Thermoplastics on the other hand can be re-melted at anytime for reshaping.

A filament winding machine takes usually monofilament, carbon composite, resin impregnated fibers and winds these filaments under CNC control around a mandrel, which represents the shape of the composite structure. After winding the composite, it is cured in an autoclave. A tape-laying machine puts resin impregnated, carbon composite, multimatrix tape of 2 inch to 20 inches width onto a mold. The tape is dispensed from a spool of tape, and it is laid out by the machine CNC control. CAD/ CAM is used commonly for the process, which improves accuracy and efficiency.

The primary benefit of composites is their lightness compared to metal. The potentials for greater strength and fatigue life are other attributes that have not reached their full technical solutions stage. In the 1970s when composites were first being tested and used in experimental aircraft, it appeared that this material would quickly substitute for metals and become the dominant material choice for aircraft in the future. All manufacturing and assembly processes would be transformed as a result. Its penetration in the marketplace has been delayed by the fact that the cost to build composite structures far exceeds currently used alternatives. The biggest inhibitor to greater use of composites in aircraft structure is the high cost of manufacturing the part, which is approximately three times greater than the alternative aluminum and titanium alloys. Herein lies a large potential market for anyone who can develop manufacturing technologies which significantly reduce costs of composite structure creation equal to or below metal usage.

Composites along with careful design attributes have a small radar signature profile, which is only useful for military purposes. Still the use of composites for military aircraft did not catch on until the development of the F117, but they have now become the dominant material of choice for military purposes. Examples are the F22 and the new joint strike fighter (JSF) in the United States, and Rafael in France. Also, composites are now widely used for rocket launch vehicles where high strength is required, and the launch vehicle is disposable. Both the military and space industries have pulled the development of composite structures and manufacturing technologies. Lessons learned from these applications are diffusing very slowly into commercial aircraft. Non-loadbearing areas of the airframe such as control surfaces are starting to use composites because of their lightweight, high strength characteristics.

One interesting experimental technology is bringing a connection with the textile industry closer to composites in aircraft manufacturing processes. The use of defined composite layouts on a 3D computer linked through CAD/CAM to a system which stitches together composite "fabric" layers is allowing fabrication of full span composite wings prior to the curing process. Although this technology is interesting, "[t]he primary concern has been the risk of damage from delamination caused by manufacturing-induced defects or by impact with runway debris, hail stones, or bird strikes. Another concern is the difficulty in manufacturing the very large composite structures required for aircraft wings at a cost competitive with state-of-the-art aluminum wings."[12] This "assembly" process demonstrates a closed loop between design and manufacturing and the usage of special software tools, for example, FiberSIM.

A recent example of composite usage in commercial aircraft is the Raytheon regional airplane. Premier I uses a composite fuselage and aluminum for the wing, spar and wing box. The fuselage is made in two parts (front half and back half) using a Cincinnati Milacron filament placement machine that wraps filament on mandrels. The composite layered mandrels are placed in autoclaves for curing. One of the problems with the Starship (a predecessor airplane that was commercially unsuccessful) was that the composite was hand-laid and not machine wrapped. This caused increased weight problems and was very labor intensive, thus high cost. Raytheon continues to believe that composites will take a key role in aircraft parts in the future. However, interviews with relevant personnel at Boeing, Airbus, and Bombardier suggest that the commercial aircraft industry will be very slow to incorporate usage of composite structures in high loadbearing areas of the aircraft. However, there will probably be some slow, steady progress in the usage of composites for commercial airplanes.

Gemcor's systems are used to install "chicken rivets" to prevent delamination of composite lap joints. The precision of the automatic fastening system significantly raises the quality of the composite fastened joint by drilling clean holes and maintaining proper countersink depth compared to manually installing fasteners in composites. However, composites significantly reduce the number of fasteners and pose a future threat to the Gemcor business as it is structured currently.

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[12] "Rapid Product Development, Shortening This Span between Design", http://www.nasatech.com/news/rgb.boeing _0125.html

Active Metals
This is a relatively new category of metallurgical research which is intended to develop alloys with or without memory for linear actuation, precision measurements, and other applications. Gemcor is working on developing a particular active metal alloy for a new fastener design to increase the strength and fatigue life of joints and resultant aircraft structure. It is uncertain at this time how much improvement these new active metal fasteners will make, but if significant, the substitution of these fasteners into airframes could further allow aircraft designers to reduce the weight comparable to that which is possible with composites, and yet not be concerned with delamination and other problems inherent with composites. Active metals could be highly complementary with Gemcor's machinery by making the systems more precise and able to adjust automatically for misalignments and/or to make precision measurements in real time. As it develops in the future, this material might provide enough linear motion and force to upset fasteners very accurately and quickly with very few moving parts.

The Influence of Joining Technologies

Snap Together Joining Process
The snap together joining process made popular by DFMA requires no fasteners for assembly. The parts have features which self-align and constrain axes of motion such that the connected parts cannot simply come apart. Shock forces especially frustrate greater use of this joining technique. It is not well suited for aircraft part joining. The definite tendency towards reduction in parts and ease of assembly or joining within the current industry has led to the snap together joining process, made popular by DFMA and requiring no fasteners for assembly. Aircraft designers have been studying methods to achieve snap together parts for aircraft structures. So far, progress has been minimal because of the zero tolerance imposed on aircraft design for structural failure due to stress and strain loads. However, anyone who can devise a clever and safe snap together methodology for metal alloys to be used in aircraft will create a tremendous cost-savings benefit to the commercial aircraft industry. Gemcor does not perceive the snap together method of joining a threat to how aircraft will be joined in the foreseeable future.

Friction Stir Welding (FSW)
The friction stir welding process presses a rotating mandrel against a seam to be welded. The friction generates heat that plasitizes the metal, stirs it together, and forms a solid state weld upon cooling. Gemcor is very keen to provide FSW systems to the aerostructures market.

Advantages:
- No pits, cracks or gas pockets
- No consumables
- High strength weld due to no solidification
- Small heat affected zone
- The Welding Institute (TWI)[13] will license worldwide patent for users
- Boeing and Lockheed-Martin have patent positions
- British Aerospace looking at using FSW to replace rivets for skin attachment to spars
- Currently used on aluminum
- Industry wants FSW for use on steel, titanium, and high strength alloys

Laser Welding
The technology of laser welding utilizes laser energy directed to multiple weld sites using physical or fiber optics.
Laser welding benefits:

[13] http://www.twi.co.uk

- Higher quality weld
- Reproducibility
- Small health action zone (HAZ)
- Speed (100 spot welds/min)
- Less rework
- No consumables
- Moderate non-recurring costs
- Robotic laser welding - current technology
- Laser welding replacing gas metal-arc and resistive welding
- Industrial interest in "Tailor-Welded Blanks" similar to quilting
- Use laser welding to "sew" together pieces of sheet metal that differ in thickness, metallurgy, or surface treatment. The welded blanks are then fed into a stamping press
- Door panels are stronger with less weight and cost to manufacturer
- Automotive
    - Honda joins inner and outer panels for 2,200 Civic doors daily using NdYAG laser system
- Potential growth area: Automated assembly system that combines laser welding with flexible fixturing assembly system

Gemcor can quickly develop an ability to offer systems with laser welding and automatic motion controls. Investigations into the best market segments need to be conducted first to assure competitive advantage.

New Technology Fasteners

There is some speculation about a single operation insert/ drill fastener. So far, the designs being used in products other than aircraft create stress risers in aircraft materials. Gemcor has sufficiently tested installation of these fasteners but has yet to thoroughly investigate the best market segments to penetrate. This technology is a potential opportunity for Gemcor's diversification efforts.

Composites Can Reduce Use of Fasteners

Composites have come closest to the elimination of fasteners and joints. However, there is a tremendous amount of work remaining and ingenuity required to completely create an assembled composite structure which has zero possibility of delamination, cracking, or damage by environmental factors such as foreign object projectiles. A market opportunity exits for Gemcor to improve with automation the cost effectiveness of producing composite structures.

Motion Controls

The influence of motion controls on aircraft production starts with linear actuators for control surfaces and also for machinery to manufacture the airplanes. Linear actuators can be either hydraulic cylinders or electric ball screws. Both can be servo controlled for precision of movement and repeatability. Hydraulics require oil, which can be hazardous to the aircraft material and the environment if it leaks, and necessitates occasional maintenance and replenishment. Electrics require infrequent maintenance of motors, amplifiers and the mechanical actuators themselves. There seems to be a trend moving from hydraulic to electric actuators to save maintenance costs and afford a cleaner operating environment. As with many technologies, there is a convergence occurring in the motion controls field of mechanical hardware, controls, sensors, and software to create intelligent systems to perform useful functions. A somewhat complete list of subcategories of motion controls can be found under the Gemcor core technologies and competencies listed in Section 2.

Information Technology Influence

The effects of information technology (IT) are very important to consider regarding the future health of the airline industry. On the one hand, e-commerce and related automated supply chain IT are creating momentary competitive advantages for airlines and aircraft companies. On the other hand, IT is experiencing a convergence of telephone, data and video Internet communication. This improved communication space will profoundly influence air travel just as it is affecting almost every other aspect of life. IT can be a complementary asset for stimulating travel and at the same time a substitute technology for flying to meet people. Paradoxically so far, the effect has been positive to the growth of air travel. Will this continue as IT becomes more mature? Scenarios of the possible future can be constructed for either positive or negative IT influences on airline travel's future growth. There does not appear to be an immediate threat. Look at the instance of distance learning at MIT on student travel. It has increased the number of times the student must travel (mostly by flying) for MIT's "business trips." Technology companies are starting to design on a global concurrent basis, and video teleconferencing between corporate sites is becoming more common. However, Michael Dertouzos states, there will be an irreplaceable, not totally substitutable, need to be in live personal contact with associates and stakeholders of all types.[14]

Could other transportation modes make a comeback – trains, ships and automobiles? Trains are still a very popular means of transportation in Europe, Japan, Russia and China. In Japan and Europe, trains are reliable, less expensive, and more convenient than air travel. Magnetically powered trains are increasing their speed. Airlines must keep their costs and prices low in these regions to be competitive. For long distance travel, the choice is obviously in favor of airlines. Train travel in the U.S. is 68 million passengers. [15]Although flying is by far the safest means of transportation, the publicity of any mishap or near accident has a very damaging effect on the airline concerned and ultimately the entire industry. Many people are still afraid to fly. Therefore, as previously stated, there is a zero tolerance in the industry for failure – hence the ultraconservatism of the industry's willingness to try new technologies until they are proven beyond doubt. There is also a cost-benefit factor and risk attached for tooling up for a new technology, which adds to conservatism.

Convergences

It is unusual that after researching futuristic aircraft designs, very few exist compared to many varieties of new design concepts that were being studied 5 and 10 years ago. These concept designs ran from large double decker aircraft ideas with combined wings and bodies, to air breathing airplanes in the atmosphere with rocket propulsion in low level space (as envisioned by President Reagon to cut travel to Japan down to 3 hours from New York). Recently Boeing and NASA gave up on a new generation SST due to the infeasibility of creating optimum designs that could stay within the aircraft price and operating costs constraints.[16]

There appears to be a creep rate of diffusion of composites into commercial aircraft, but the aforementioned dual impediments of fabrication costs and delamination and projectile strike material weaknesses have held back the diffusion. Ergo, improvements in these three areas will make important contributions to the success of composite materials in commercial aircraft.

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[14] What Will Be: How the New World of Information Will Change Our Lives, Michael Dertouzos, 1997, HarperCollins

[15] Anthony Pl Lee, April 21, 1998, www.o-keating.com/features/hslwwwboard/message/71.htm.
By 2020, High Speed Ground Transportation will increase by a factor of 4 in the California and Northeast corridor. Ref: Commercial Feasibility Study of HSGT - Fed. Railroad Adm. report - 1996

[16] "Successor to Concorde can't get off the ground", Science, *USA TODAY*, April 6, 1999, page 8D

Safety and then cost efficiency are the driving forces in the industry. Airlines will not take risks. Lack of risk taking hampers the rate of technological advances. However, if fuel prices were to dramatically and permanently increase, then composites or new technologies might be used or substituted more readily.

Conclusions

"If it can happen technically, it will!"[17] This statement leads to the prediction that polymer composites will eventually become the dominant or even the entire material used in commercial aircraft in the future. Technological solutions will be found to prevent delamination, cracking and compression damage primarily by knowledge transferred from the experiences with military applications, which have adopted plastic composite technology at a faster rate than commercial aircraft design. However, current aircraft designs being produced by both Airbus and Boeing will continue to be produced over the aircraft's lifetime, anticipated to be 20-30 years. Any future designs to be launched in the large and the regional commercial market segments will utilize increasing amounts of composites. Therefore, it is also a conclusion that fastener usage will be significantly reduced over time. Therefore, Gemcor over the next ten (10) years must diversify to reduce its dependence on the commercial aerostructure market segment. It must discover future technological applications in new products for its sustaining prosperous future.

Planning for the Future – or – Anticipating the Future

The Trajectories and Evolution of Mechanical Fasteners Used in Commercial Aircraft

Figure 3.4 overlays several competing or influencing technologies in the aircraft industry. The S-curve time, magnitude and substitution depictions are based on the latest research, publications, and experience in the aircraft industry. The HVM and composite technologies are at a much higher trajectory than aluminum automatic fastening. Aluminum riveting could have actually shown a declining line.

It can be predicted that rivets and mechanical fasteners used in commercial aircraft will be diminishing rapidly beginning after the year 2010 as a result of the greater usage of polymer composites and high-speed machining. There is speculation that materials will be "grown"[18] in the future, becoming the prevalent form of composite "self organizing" structure manufacturing 30 to 40 years from now.

[17] Only the Paranoid Survive, Andrew Grove, 1996, Bantam Doubleday Dell, audio version

[18] "Innovations in Polymeric Materials", Edwin Thomas, Department of Materials Science and Engineering, M.I.T., May 1998.

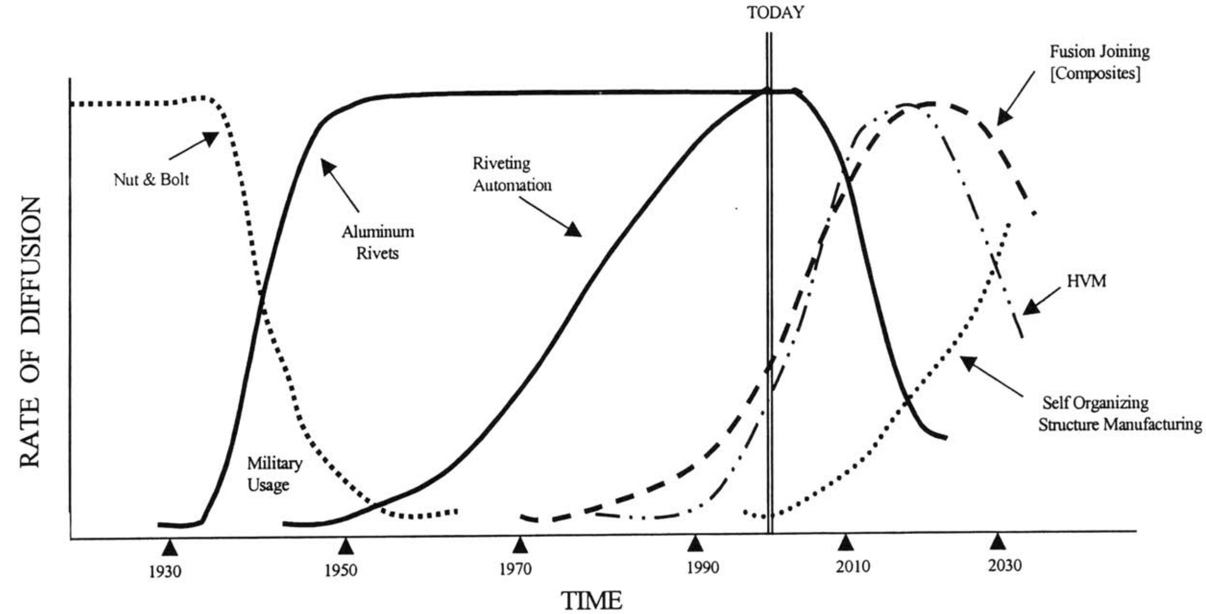

Figure 3.4 Technology Trajectories and Evolution – Mechanical Fasteners used in Commercial Aircraft

Figure 3.5 shows the technology trend of mechanical fastening elimination in commercial aircraft. Mechanical fasteners in commercial aircraft are composed of two basic types: solid rivets and two-piece fasteners. They will be replaced by the technological change forces of fusion joining, high velocity machining, DFMA, and the integration of parts.

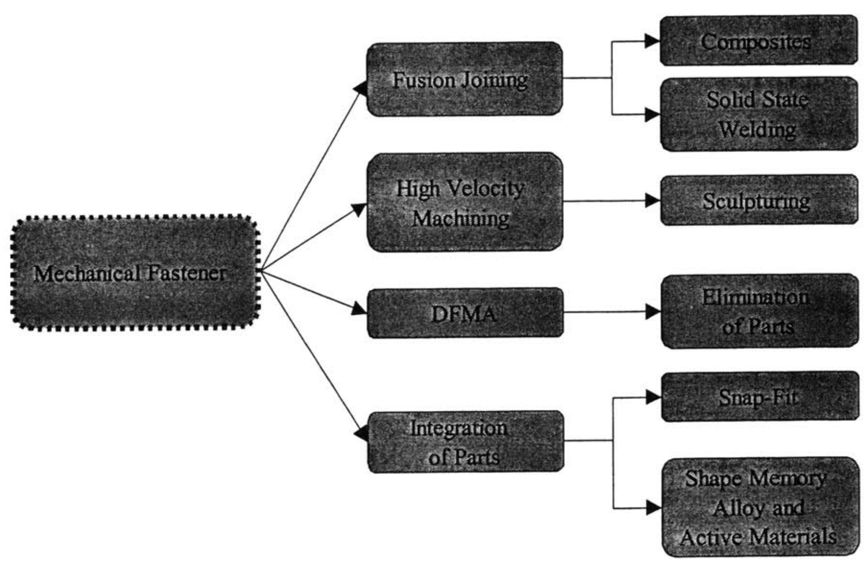

Figure 3.5 Technology Trend – Mechanical Fastener Elimination in Commercial Aircraft

The Recommended Technology Strategy for Gemcor (Opportunity Space for Technological Change Improvements)

The use of fasteners in commercial airplanes and the need for automatic fastening will not be substituted immediately by other technologies,[19] but the pace of technological substitution is quickening. Composites will become dominant. It is recommended that Gemcor enter the markets for making automation systems for creating composite aerostructures using both lay-up and filament winding machinery. A creative start could be the development of programmable flexible molds for creating the shape of the composite structures, effectively linking design and manufacturing by CAD/CAM. Another suggested pursuit is the actual manufacture of composite aerostructures as an outsource contractor for prime aircraft manufacturers. A further suggestion is to become a rapid prototyper of composite structures using automation. Aircraft companies have the need for initial low part production of new designs to conduct tests. (See Figure 3.6). Finally, it is recommended that Gemcor begin the design and manufacture of high-speed machine tools for the machining of aluminum and titanium monolithic billets, adapting this know-how for friction stir welding and for flexible fixturing.

As a result of this analysis, the company is requesting that its customers place Gemcor on their bid lists for quoting composite structure manufacturing automation systems (CSMAS). Additionally, Gemcor is identifying certain engineers from at least Boeing, Airbus, and Lockheed to separately discuss problems and their current and anticipated future wants in CSMAS, beginning with the voice-of-customer (VOC) definition process. (See Figure 3.7). Selected individuals at these customers will work part-time with Gemcor to conceive of a product line to meet the VOC. Specifications and market target pricing will then be developed and agreed upon. Finally, work statements, including Catia solid modeling of concepts and functional leaders' budgets and schedules along with formal buy-in agreements will be completed. (See Figure 3.8).

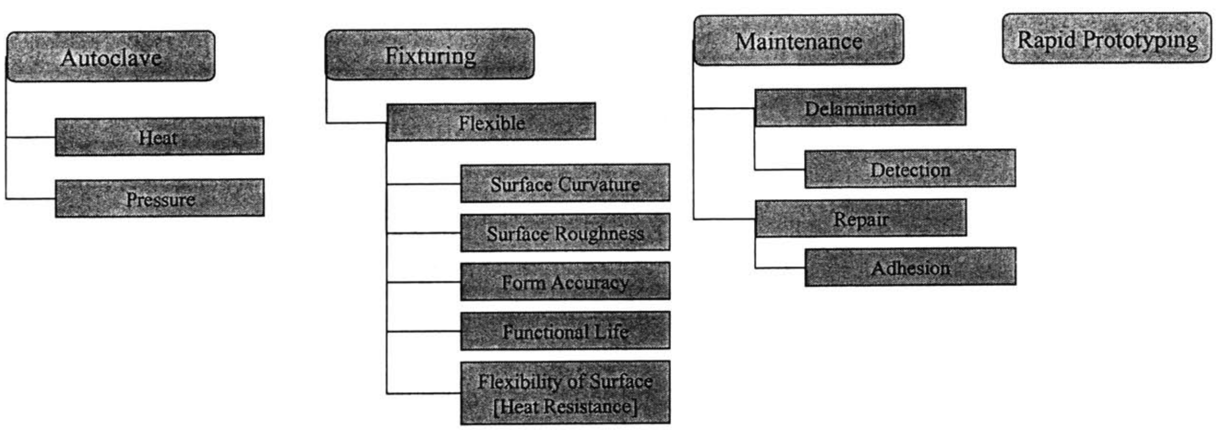

Figure 3.6 Composites – Manufacturing Opportunity Space for Technology Improvements

[19] A discovery from this technology strategy analysis is that the Gemcor Escrst™ new product line appears to be well positioned to support the commercial aircraft assembly requirements through 2010. (See Section 7)

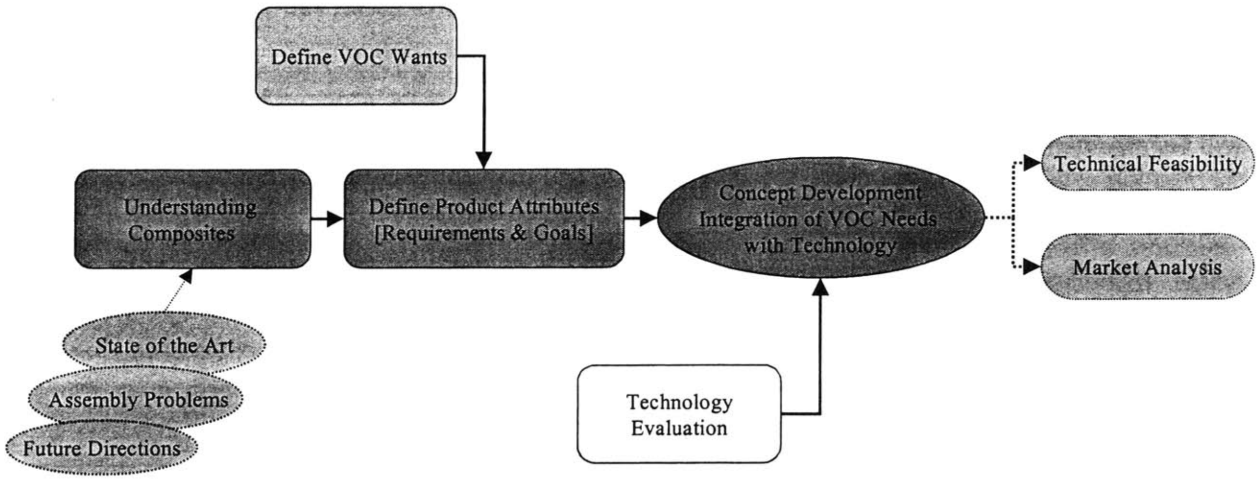

Figure 3.7 Developing Composite Structure Manufacturing Automation System Solutions to Aerospace Wants

VOC PRODUCT DEVELOPMENT PROCESS

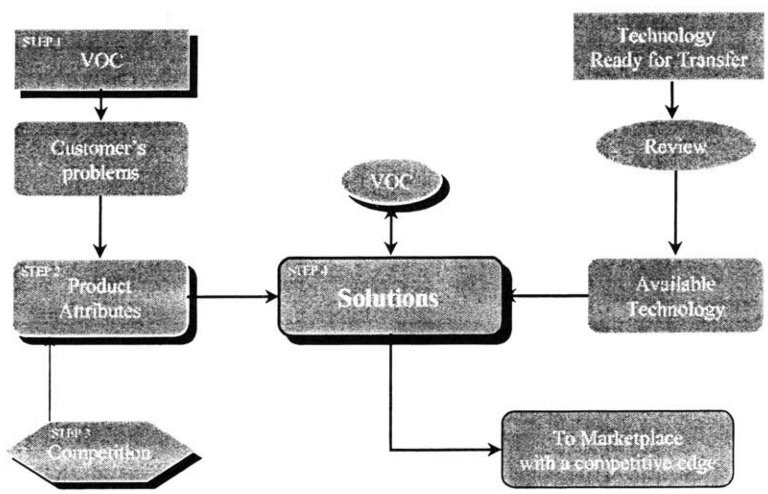

Figure 3.8 Gemcor's Product Development Process [Basic]

Section 4

Industry Trends and Demographics and their Effect on Gemcor

Gemcor is most affected by new airplane launches since normally there is a coupled requirement for new automatic fastening machinery and fixtures. The commercial airplane market space is dominated by very few producers. Understanding how the market influences these new airplane launches and in turn the airplane producers' needs and requirements for automation machinery is paramount to competing successfully in Gemcor's market niche. On the immediate horizon are the launches of the very large transport aircraft (VLTA), the A3XX, and counterpart derivatives of the 747 and 777 by Boeing. The European military cargo aircraft called the A400 is also projected to launch imminently.

State of the Aerostructures Industry

The market space is characterized by an almost equal sharing duopoly by Airbus and Boeing for large commercial transports, Bombardier as the dominant regional jet producer with encroachment possibilities into the large transport market, and probable production of large transports by Asian producers. The state of the market is well analyzed by Airbus and Boeing in their annual forecasts.

Historically, Boeing has been the market leader, but Airbus is now challenging this dominance. In the high end market Boeing enjoys a monopoly with the 747 since Airbus has no equivalent platform. Two separate market forecasts (Boeing and Airbus) project that passenger traffic will grow between 4.3% and 5% over the next 20 years and that cargo traffic will grow between 5.9% and 6.4% over the same period of time. The market is being driven by rising oil prices, rising global GDP's, consolidations and alliances of airlines into market controlling mega airlines, passenger traffic growth, traffic growth stimulation by e-commerce, increasing air cargo, air space and airport congestion from frequent smaller jet flights, passenger demands for short time and on time travel at lowest fares, geopolitical factors influencing aircraft order decisions and environment of restrictions, age and replacement rates of aircraft, and improved travel safety. These combined parameters are driving the need for more efficient aircraft, which at the same time is constrained by new product development time-to-market, return on investment, and company and shareholder risk tolerance. Boeing and the regional jet producers prefer as a solution the paradigm that frequent flights of smaller aircraft are more economical. However, there is the equally arguable possibility that fewer trips between high-density pair cities with the VLTA will simultaneously satisfy these parameters. The analysis provided herein suggests that a positive business case exists for the VLTA.

The rising global GDP's and greater use of e-commerce are primary causes for the passenger and air cargo growth. As has been stated, jet fuel is the highest component cost to the airlines and creates the demand for greater fuel-efficient engines and improved aerodynamic aircraft designs to lower costs per seat and cost per kilogram. Therefore, world oil prices are the key barometer of this cost. The mega-airlines may be the only customers who are able to afford the VLTA. Airline competition to create competitive advantages is intensifying, causing consolidation among the airlines to achieve economies of scale to create operating efficiencies and to control the market better, especially on the high traffic routes. One effect of the intense competition is that loyalty between airlines and the aircraft manufacturer seems to be diminishing.

Economic Influences

The world's economy is strong due to the positive impact of the strength of United States economic growth. The world's growth rate will be almost doubling over the next several years from 2.2% to 4.3%. Real commodity prices are falling by 5% while oil prices which rose over the past year due to production curbs by the Organization of the Petroleum Exporting Countries (OPEC) will stay steady over time. Interest rates will hold at 3%, and inflation will drop to 4% (3% in advanced countries).[20]

Regional Economies

United States

The U. S. market has been growing robustly with real GDP at 4.2% for 1999, 4.4% for 2000, and 3.0% for 2001. Inflation is 1.5% for 1999, 2.0% for 2000, and 2.3% for 2001, and unemployment is 4.2% for 1999, 4.2% for 2000, and 4.2% for 2001. The national debt has been reduced, and the balance of trade had narrowed last year but is widening again. There are greater numbers of workers and jobs than ever in history. Inflation is increasing at half the rate of income growth. The Dow Jones Average has surpassed 10,000. Credit is at an interest rate low and is readily available. The Federal Reserve Bank is keeping interest rates steady.[21] Consumer confidence is at a high. Last quarter's growth was 6% driven primarily by the consumer sector. A concern is the low level of individual savings, high personal debts[22], and the high priced stock market. A rapid downfall in the stock market would have a downturn effect on the U. S. and world economy.[23] Corporate profit margins have fallen and are the only negative sign, which has partially caused the recent stock market volatility. [24] A strong U. S. economy is directly related to higher airline passenger rates and industry growth. The U. S. airline travel market also significantly influences and often drives world travel rates and growth.

United Europe

Led by Germany the United Europe has been growing with a GDP at 2.3% for 1999, 3.2% for 2000, and 3.0% for 2001. Inflation was 1.6% for 1999, 1.7% for 2000, and 1.7% for 2000, and unemployment was 8.9% for 1999, 8.4% for 2000, and 8.0% for 2001.[25]

Japan

Japan's economy has emerged from its downturn and will be improving due to judicious fiscal stimuli. The Japanese GDP was –2.5% in 1998, but was 0.3% in 1999 and is projected to be 0.9 in 2000 and 1.8% in 2001.[26]

Asia other

Although there is still a long way to go for recovery, it is believed that Asia is also at the trough of its downturn and will begin improving.[27] The Asian economic crisis has affected only seven percent of the global traffic. This effect has rapidly diminished with a notable turnaround -- real GDP is expected to be 6.2% in 2000 and 5.9% in 2001. The inflation rate is forecast to be 2.6% in 2000 and 3.0% in 2001.

Russia

Difficulties in Russia are severe due in part to its lack of efficient tax collections to provide revenue to pay international debts. After the debt restructuring, tax collections and monetary policies were working but fell apart in August 1998, which created a crisis. Inflation was running at 110% and is expected to reduce to 28% in 2000 and 20% in 2001 due to budget constraints, increased tax payments, exit of nonviable companies, and a strengthened legal system.[28] The 1998 GDP was negative but rebounded to a

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[20] World Economic Outlook, International Monetary Fund, May, 2000, P. 1-4 and 57.
[21] WSJ, Nov. 15, 2000, "The Federal Reserve voted to hold interest rates steady and gave no indications it would lower rates anytime in the near future."
[22] Ibid., p.103 and 114
[23] Ibid., p. 214
[24] "It was the Best of Times", *Business Week*, April 12, 1999.
[25] Ibid., p. 106 and 207
[26] Ibid., p. 2 and 16, 17
[27] Ibid., p. 23, 28-30
[28] Ibid., p. 203 and 214

positive 3.2% in 1999 and should be 1.5% in 2000 and 1.4% in 2001. Russia had followed just behind Boeing in production level of aircraft, but not since becoming a free market economy. The Russian aircraft industry is struggling badly. The question is whether they will ever become a world class producer of aircraft. Fiscal constraints and impediments continuing from remnants of the old planned society are preventing the modernization steps in technologies and management. Russia is currently not stable enough to become a valued, high quality subcontractor.

India
The GDP of India grew at 6.8% in 1999 and is expected to be 6.5% in 2000. Inflation was 5.0% in 1999. Of note, transportation has a very important role in economic growth for developing countries because of the ability to transport people and cargo efficiently, attracting corporate and tourist dollars.[29]

China
The Chinese economy is growing at 7.1% and seems to be stable with respect to other Asian economies. Its growth has been created in part by governmental spending on infrastructure. The inflation rate in 1999 was –1.4%.[30]

Commercial Aircraft Market Economics and Forecast
The Influence of Oil Prices
The price of oil has a direct effect on fuel costs to airlines. Fuel prices are usually the number one cost to airlines yet its effect has been reduced by the huge improvements in jet engine fuel economy, GPS positioning (which makes routes faster and lowers fuel consumption), and improved wing and airplane design with the use of advanced fluid dynamics analysis software tools, which is very impressive.[31]

Passenger to Seat Availability Loading Factors
Load factors for both large and regional airlines are usually running at 69 percent or higher, which is well above the breakeven point for airlines. Thus, airlines are very profitable for now and have grown at 20.3% over the last five years. Airline stocks are doing well again with British Airways, for instance, at a "strong buy" recommendation amongst analysts in the industry at $8.39B.[32] The load factor trend for the future is considered to remain constant.[33] Likewise, Boeing's stock price has significantly rebounded for these reasons and for their operational efficiency improvements.

Global Market Forecasts for Commercial Aircraft by Airbus and Boeing
Surprisingly there has been a minimal impact caused by the past Asian economic distresses on the worldwide expansion of air travel. By comparing the 2000 forecast reports of Airbus and Boeing, we can sense potential trends in overall air travel and demand by market segment, and then by product type comparatively.

The total passenger traffic growth in revenue passenger miles forecasted by both companies shows an expected average annual growth rate of 5.2 percent for 10 years and then will slow to 4.6% as the market matures in the subsequent 10 years. The annual passenger traffic growth rate through 2019 is expected to be 4.9%. The total demand for commercial aircraft of all types over the next twenty years is 23,000. The cargo market is expected to grow at 6.1% measured in freight ton miles for the first 10 years then 5.3% for the next ten years for an average of 5.7% through 2019.

[29] http://www.aerostock.com/secure/Nov1.html, p. 2
[30] Ibid., p. 10 and 219
[31] "The New Horizons of Aerospace", Harry Abruzzese, http://www.techstocks.com/~wsapi/investor/newsletter-46, p. 1, 2000.
[32] http://biz.yahoo.com/z/a/b/bab.html
[33] Aerospace Corporate Research Inc., March 5, 1999, P. 1-7, http://www.aerostock.com/secure/mar1.html

Airbus and Boeing expect that intermediate size aircraft will be the fastest growing segment because these midsize airplanes are now capable of extending to long-range intercontinental markets, cannibalizing some of the 747 market, and because of the strong regional traffic growth which takes business away from the single aisle aircraft for intermediate size. However, there is disagreement between the two companies concerning large aircraft. Boeing believes that competition, network development, and economics force a growth in frequencies but not aircraft sizes, whereas Airbus believes that there will be a growth and a demand also for efficient very large aircraft.[34]

An information technology has significantly enabled airlines to integrate scheduling, pricing, distribution, impact of and yield management strategies for filling more off-peak seats. It is anticipated that passenger load factors will rise from 69.6 percent to 72.6 percent as a result of the increasingly sophisticated computer reservation systems, which provide airlines a potential competitive advantage.

Regional Aircraft Market
This market can be described as the 19-90 seat market. Passenger traffic for this market segment is growing at an average projected 10-year annual rate of 7.7 percent with 80 percent of the planes using jet engines (turboprop usage is on a fast decline).[35] Regional aircraft production will probably be the faster growing segment due to the replacement of turboprops with jets.

Airplane Producers' Transitions
Three years ago Boeing acquired McDonnell Douglas Aircraft and experienced absorption difficulties. However, these combined corporations now create a super buyer from Gemcor's perspective. In the short run Boeing will not be leveraging this power due to other priorities, but in the future they will have great leverage in purchasing at best prices and values from a few surviving competitive suppliers. In the near-term Boeing clearly needs help in cost reduction.[36] Members of the Airbus consortia have merged. British Aerospace and DASA have also discussing merger, and simultaneously British Aerospace has been conducting similar merger talks with General Electric Aerospace. Another interesting commentary has been that Boeing might spin-off the commercial airplane business entirely to General Electric. Any or all of these organizational and power changes will have significant effects on the production of airplanes in the future with respect to suppliers.

Geopolitical Considerations and their Effects on the Functional Requirements of the VLTA
Geopolitics affects every aspect of functionality within the commercial aircraft worldwide system dynamics. The geopolitical factor in aircraft sales in general, and more specifically for the VLTA, will continue to play a huge role as it has historically done in the marketing and sales of both Boeing and Airbus commercial aircraft products. Geopolitics will certainly affect the VLTA. The subject is well portrayed in the book Birds of Prey, Boeing vs. Airbus a Battle for the Skies.[37] Airbus now is making

[34] "Review and Comparison of 1998 Airbus Industries Recast Hand Boeing Current Market Outlook", http://www.4 tourismfutureintl.com/resources/airbus-boeing.html
[35] "Forecast of the U.S. Regional Airline Industry: 1998-2008", http://www.raa.org/carriers/98forecast.html, pages 3 and 4
[36] "Fearless in Seattle", *CFO* April 1999; interview with Boeing's new CFO
[37] Birds of Prey, Boeing vs. Airbus a Battle for the Skies, M. Lynn, Reed International Books, Ltd., 1998. This book really should be essential reading for anyone interested in commercial aircraft systems engineering. It covers nearly all of the geopolitical considerations as background leading up to and including the A3XX. The author also provides a very well constructed history of commercial aircraft beginning with the Wright Brothers and then the start of commercialization of air travel in England led by Geoffrey DeHavilland and the German Willi Messerschmitt. Historically, the intertwining roles of government, airlines, aircraft producers and regulations are described in almost a literary quality manner. All these complex forces are occurring while Boeing and McDonnell Douglas are trying to make money for their shareholders.

money for its partners and participating governments through its Airbus family of airplanes. Boeing's attempt to make exclusive sales deals for the next 20 years with Delta, Continental and American Airlines was thwarted by the European Union and a Boeing concession during its merger approval with McDonnell Douglas. Without this concession, Boeing may have prevented A3XX from launching. [38]

Entire governments are involved in the high stakes selling of their countries' aircraft products. The General Agreement on Tariffs and Trade (GATT) is an imperfect means of setting the ground rules for international trade, particularly by the United States and Europe; however, GATT also extends to all participating countries who "abide by" the agreement. Under this agreement, the European Union (EU) is formally allowed to subsidize 30 percent of the development costs of new airplanes for Airbus. The United States uses NASA and military technology developments to subsidize Boeing's technological developments. Under GATT there is a Foreign Sales Corporation (FSC) allowance, which is embedded in the Internal Revenue Service code, allowing all foreign sales by United States domestic corporations to be treated in a lower tax bracket than sales within the United States. This IRS special tax treatment for foreign sales is intended to help U.S. corporations compete more effectively against the European and other country subsidized corporations.[39] It is common for both the EU and Airbus, as well as the United States and Boeing, to link their influence to persuade the airplane purchase decisions of different countries' airlines. For instance, when a country receives grants and subsidies from either the European Union or the United States, the subsidies can be used, by threat of withdrawal, to force the purchase from either Airbus or Boeing.

The mergers, acquisitions, and alliances of international airlines into mega-airlines should have a dampening effect on the United States and European Union influence tactics and shift more power for self-determination of aircraft purchases to these mega-airlines themselves. As stated by Mr. Howard Aylesworth,[40] Director, Airworthiness and Regulation, domestic and international antitrust laws will not affect these mega-airline consolidations. These new airline oligopolies will have power to force both Airbus and Boeing to compete until there is no money remaining on the table, no profitability amongst the airplane producers. However, momentary competitive advantage may lie with the aircraft producer who has lower cost airplanes with more efficient operating costs along with very attractive financing options. The buying power of these mega-airlines will be substantial. Also, these airlines will exhibit substantial influence over airport and air traffic control infrastructure. These mega-airlines will bring substantial economic gain to those municipalities which agree to their demands by bringing more passenger traffic and cargo traffic into their economic zones. However, governments and airports (Air Traffic Management and Control on the ground and in the skies) will still have their own power due to the populace in the dense city pairs.

To keep operating costs and ticket prices low to drive out other airline competitors, the mega-airlines should be attracted to buy the VLTA, which smaller airlines probably will not be able to afford, for market traffic control and dominance between these dense city pairs. Therefore, it appears that the trend towards creating mega-airlines is the historically natural economic occurrence, competitors consolidating to gain market control over prices and supply chain costs.

Another geopolitical influence is OPEC, which controls the supply and price of oil and is one of the key externalities controlling both airlines and aircraft producers' profitability. A rise in oil prices favors more fuel efficient aircraft, which because of the fuel efficient specification intent of the VLTA should give it a preferred position, as would extended-range twin-engine operations (ETOPS) airplanes. Airspace has

[38] Ibid., page 232.
[39] The FSC type corporation will not be allowed after November 2000 due to European GATT pressures on the Untied States.
[40] Director, Airworthiness and Regulation, Aerospace Industries Association of America, lecture to MIT Aircraft Systems Engineering Class, March 2000.

become a geopolitical/economic factor. Countries such as Russia are playing a tough negotiating hand to gain technologies (i.e., GPS navigational system), money, and other economic incentives. It is reported that an over-the-Russian-airspace border long haul route can save airlines up to $50,000 per flight.[41]

An interrelated externality with geopolitical considerations is political stability. When a war breaks out, air traffic is usually negatively affected. A related geopolitical factor is terrorism. Those entities who feel they are being mistreated or want to send a political message use extreme actions such as aircraft terrorism to gain immediate importance. This threat will cause aircraft structural designers to create antiterrorist protection countermeasures to prevent catastrophic failure of the aircraft in the event of a terrorist act on the airplane.

The corporate structure of Airbus has changed considerably reflecting the consolidating of the united countries of Europe. The new company is called European Aeronautic Defense and Space, N.V. (EADS). The structure is a fusion of companies shown in Table 4.1.[42] The new company ownership is DaimlerChrysler 32.70%, French state 16.10%, Lagardere 11.10%, Spanish state 5.48, BNP-AXA 3.90%, and the general public owns 30.65%. EADS in turn owns 80% of Airbus, and the remaining 20% is owned by BAE Systems.

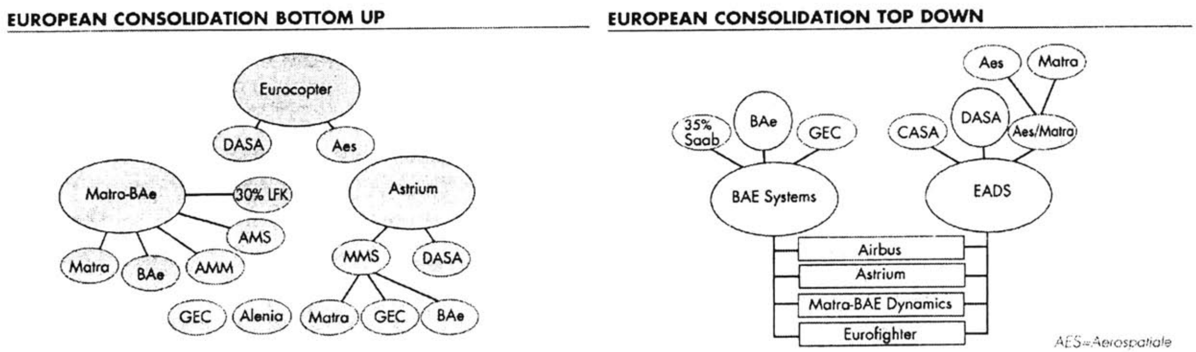

Table 4.1 European Aeronautic Defense and Space, N.V. (EADS)

The Airbus contribution to EADS' EBIT[43] financial projections are:

Airbus's contribution to EADS' Operating Profit

Euro million	1999	2000E	2001E	2002E	2003E	2004E
Former estimates						
Operating profit	896	825	815	1,040	1,180	1,480
Operating margin	7.1%	6.8%	6.5%	7.2%	7.6%	9.1%
Estimates incl. Airbus' new production rates						
Operating profit	896	884	891	1,365	1,718	2,036
Operating margin	7.1%	6.9%	6.7%	8.2%	9.0%	10.2%

Source: Deutsche Bank estimates

[41] Quoted from Professor R. John Hansman from his lecture, "Air Traffic Control Issues Associated with Very Large Aircraft", presented on March 13, 2000.
[42] "Defense Industry Challenges: A European Perspective," *Aerospace America*, AIAA, August 2000, Pp. 32-37.
[43] http://www.finance.eads-nv.com/deutbkuk.pdf , October 2000.

Competitive Influences

Competition has driven down prices and profits of Boeing and Airbus so that Boeing is at best making 1% profit on its huge backlog.[44] Drastic improvements are needed to improve competitive advantages and margins. This is a huge area of opportunity for those who can significantly help these companies reduce their costs.

As a counter to the A3XX, Boeing preliminary specifications are for two alternative versions of this new large aircraft. One is an extension of the 747, which would be simpler, lower-cost, and faster in time to market. The other is dubbed the 763 model, an all new airplane that would have four engines, three aisles, but not the hunchback 747 profile. Instead, the aerodynamics will be enhanced by a constant width fuselage design and other improvements, including laminar flow nacelles, riblets, and programmable flaps, which would result in an estimated 2 percent reduction in drag compared to the 777. More radically, Boeing intends to produce a composite wing spar box which will save 20 percent in weight compared to one manufactured out of aluminum. The empennage also would be made out of co-cured graphite composite similar to the 777. The use of composites in the airplane external and interior structures is intended to save 3000 pounds compared to current transports. Boeing also intends to more heavily employ advanced manufacturing technologies of monolithic or chemical-milled fuselage panels similar to the 777 and high-speed machining techniques. The floor beams will be carbon composite.

Meanwhile, Airbus has been courting Japan on the A3XX to participate in the main wing development as a risk-sharing partner. Mitsubishi Heavy Industries is already assembling main wing parts for the British Aerospace Airbus A319/A320, and Kawasaki Heavy Industries is making A321 fuselage panels.[45]

Competitive Market Space

The market space is assumed to be as shown in Figure 4.1. One of the markets considered is the large commercial airplane market, which is served by aircraft with more than 100 seats. The other market is the regional aircraft market served by aircraft with less than 100 seats. The large airplane market is composed of two major commercial aircraft manufactures, Airbus Industrie and the Boeing Airplane Company. Airbus has over 50 percent market share and is growing, whereas the Boeing Airplane Company has been losing market share and is reducing production as well as associated resources. At the low end of this market are regional jet producers including Embraer and Dornier, and led by the well-managed, high growth company – Bombardier. All of the three regional manufacturers are launching new 115 seat aircraft and are encroaching into the large airplane market. These regional manufacturers have exhibited growth and profitability, whereas both Airbus and Boeing have weak profitability at the low-end of the product line. The competitive behavior is reminiscent of classic cases such as the Canon encroachment into the Xerox copier market from the low-end and Canon's subsequent growth to become a major competitor to the industry leader. This encroachment by the regional airplanes and Bombardier in particular needs to be considered for possible future ramifications to Airbus. Wild card possibilities for large airplane production include aircraft corporations in Russia, China and Korea. The term 'wild card' is used here since it is assumed that due to their political and economic circumstances these countries and their aircraft producers will not become independent world-class large aircraft producers within the next ten years.

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[44] Ibid.

[45] "Boeing Hones New 550-Seat Transport Design", *Aviation Week*, Paul Proctor, http://www.aviationweek.com/aviation/avi_air.htm

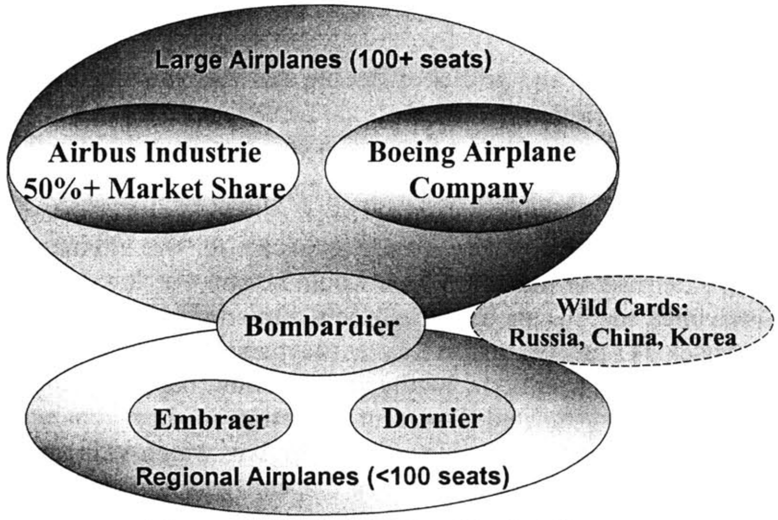

Figure 4.1 Competitive Market Space

A Comparative Analysis of Boeing and Airbus

The Boeing Commercial Airplanes Group

- Used to be the dominant seller/ producer of airplanes in the world, noted for superior management in airplane design and low cost manufacturing, and a daring technology leader as evidenced by the 747.
- Is a publicly owned company.
- Two years ago it lost over $2 billion in its acquisition of McDonnell Douglas and its less than successful attempt to adopt Toyota manufacturing principles and techniques, such as JIT.
- In its history, the 747 development almost bankrupt the company, which may have set the tone for the past 25 years of conservatism. Since the 747, Boeing has successfully launched the 757, 767, several family members of the 737, and the digitally modeled, simulated, ground breaking 777. The 777 utilized latest computer aided design techniques to save airlines' operating costs. The only negative pronounced is that the seat pitch is too narrow and uncomfortable. The 757 single aisle has also come under this same criticism. The 717 was acquired along with the McDonnell Douglas acquisition, but it uses the DC9 wing, and its cockpit is not in line with the other Boeing designs. Its wing production is being moved back to Boeing Canada from Korea for supply chain control.
- Boeing used risk-sharing partners in Japan (KHI, MHI, and FHI)[46] for the 777 production. These same subcontractors made fuselage panels for the 767.
- Boeing seems to be investing in military, space and electronics to create profitable growth since commercial airplane business has been marginally profitable.
- Boeing has tried to diversify unsuccessfully by entering the regional aircraft market with deHavilland, which it abandoned to the Canadian government, and in turn passed it to Bombardier which is successfully operating the company. Boeing also has tried such product/ markets as airfoils and hydrofoil ships.
- Boeing is discontinuing, retiring over time the McDonnell Douglas designed commercial aircraft family. Many of these models are redundant or inefficient with respect to today's standards of low cost build efficiency and operating performance and compared to the other Boeing family models.
- Boeing's attitude seems to be the "glass is half empty."
- Boeing seems to have a profitability weakness on its smaller aircraft.
- Boeing still has great management and processes. They know how to build airplanes at low cost. Recently Boeing brought back retirees to work with them to reinstitute some of the unfortunately disbanded systems which had made Boeing profitable in the past.

46 Kawasaki Heavy Industries (KHI), Mitsubishi Heavy Industries (MHI), and Fuji Heavy Industries (FHI)

- Boeing had a new Chief Financial Officer who exerted financial due diligence pressures throughout the organization to eliminate waste and create profitability. The past year has shown the financial benefits. However, it appears some of the benefit was obtained by an immediate spending halt, which might have future competitively negative consequences by not investing in improvement technologies to sustain competitive advantage. Recently, the CFO resigned and was replaced by an operating manager who should be more sensitive to investing in Boeing's future.
- The company is based in Seattle, Washington. Boeing has considerable political and economic clout in state, congressional and executive realms due to its large U.S. wide employment and the fact that Boeing is the largest exporter for the U. S. and contributes greatly to the U.S. balance of trade.
- Boeing does not seem to believe that mega-airlines will be formed with enough demand to justify development of a Very Large Commercial Transport Aircraft (VLTA).
- Boeing envisions frequent single aisle airplane flights from point to point whereas Airbus envisions large consolidated hub networks using larger capacity aircraft.
- Cash-on-hand for investments is about $7 billion and further funds can be raised, but not easily or cheaply, in the stock market and by bond issuance.

Airbus Industrie

- Risk sharing partners – British Aerospace, Aerospatiale-Matra, Deutsche Aerospace (Daimler-Benz), and to a lesser investment Alenia and CASA. Aerospatiale-Matra, Deutsche Aerospace (Daimler-Benz) and CASA plan to merge this year.[47]
- Can receive 33% European Union subsidy per agreement with the United States.
- Has overtaken Boeing in world market share for the first time in 1999.
- Aggressively wishes to overtake the 747 cash cow of Boeing to weaken Boeing and claim market superiority for competitive advantage.
- Has no public financial accountability.
- Their attitude seems to be the "glass is half full."
- Very willing to try new technologies and has been successful in so doing. Examples are the fly-by-wire which Boeing said was unsafe before Airbus proved otherwise. This technology is a key differentiator between Airbus and Boeing. Airbus is exploiting its flexibility to make the cockpits of its aircraft family look and feel the same for ease of pilot training and conversion from one plane to another while probably enhancing safety due to the commonality of design. The fly-by-wire technology and cockpit displays enables single type rating (STR) for the aircraft family fleet and ease of transferability of the pilots and crew from one aircraft to another in the Airbus airplane family — cross crew qualification (CCQ) and mixed fleet flying.
- The company is based in Toulouse, France. Airbus has considerable political and economic clout within the European Union due to its large employment especially in the United Kingdom, France, Germany, Italy, and Spain.
- Airbus was a pathfinder for usage of solid modeling, simulation, and collaborative design by the nature of its risk sharing, geographically dispersed, major component producers.
- For the VLTA, Airbus is assuming large hub and spoke air traffic network design based on the assumptions and current evidence of airlines merging, acquiring or creating alliances to form mega-airlines. The VLTA, which could only be afforded by such mega-airlines, will dominate the future high-density traffic routes.
- Investment funds are available from the European Union, partner shareholders, and risk sharing partners.
- Risk sharing partners for the VLTA include the Airbus Consortium: British Aerospace, Aerospatiale-Matra, DaimlerChrysler Aerospace, and CASA (acquired by DaimlerChrysler Aerospace) plus other risk sharing partners: Alenia, Belairbus, Fokker Aviation, Saab and Finnaviatec.[48]

The VLTA turn around time must be comparable to the 747-400.

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[47] "Airbus claims to have outflown Boeing", *Financial Times*, January 14, 2000, page 9.
[48] "Airbus exec: A3XX should fly", S. Holmes, *Seattle Times*, October 7, 1999.

Airbus Product Family Profile
The Airbus possesses a full family of airplanes which have modularity and extensibility built in their system architecture. The product family is divided into market segments of small (>100 seats), medium and large categories. Each category has a standard wing with minor adaptations for extra lift for larger derivatives and for extra fuel carrying capacity to extend the aircraft range. The aircraft are designed to accept any right sized engine from any major engine manufacturer in the world. All product categories have a standard cockpit, standard look, and fly-by-wire characteristics. This cockpit commonality eases crossover of flight crew from one type of aircraft to another. Each category has one baseline aircraft with several derivatives distinguished by modular plug in fuselage sections designed to meet payload/range requirements.

A Potential Threat to Airbus Industrie's Business Growth
Currently Boeing has a strong competitive advantage over Airbus in the large aircraft category with the 747-400. This is the only aircraft in the world fleet that serves the large aircraft market. Hence, Boeing has 100% of this market share. The market forecasts also show that this market is still growing and is far from reaching saturation. Likewise, since Boeing has already sold more than 1,100 747s over the last 30 years[49], it can be safely assumed that an aircraft of this size and performance is accepted, needed and appreciated in the airline industry.

Airbus is losing market opportunity by not having an aircraft to compete with Boeing in this market segment. Airbus has gained market share in smaller narrow and wide body segments. However, Boeing can effectively take over Airbus Industrie's increasing market share by reducing the prices on their smaller aircraft and subsidizing the rest of the programs with profits from the 747. The 747 program has already reached break-even point, and every 747 sale has a direct contribution to Boeing's profits. Boeing can increase 747 prices slightly and reduce the prices of the smaller aircraft to compete with Airbus in price. Since the 747 is the only aircraft that serves the market need, Boeing is in a position to raise the 747 price and still not lose demand. With aircraft acquisition cost being one of the important considerations in investing in an aircraft for an airline, Boeing can execute this pricing strategy if they choose, and effectively diminish the Airbus market presence over time.

The best manner by which Airbus can prevent market loss is by having a product to compete with the 747 head-to-head. Without a product to reduce Boeing's domination in the large aircraft market, Boeing's strategy of cross subsidizing the rest of the programs with the 747 can force Airbus Industrie's market share to decrease severely and its business growth to stifle over the next 20 to 30 years. It is in Airbus Industrie's best interests strategically to take any reasonable risk and develop a new large aircraft to compete directly with the 747 to protect and enhance its market share and profitable business growth. The investment can be justified simply by noting that the 747 market is growing, Airbus does not have a product to satisfy this segment, and Boeing has a product that can be used to stunt Airbus Industrie's growth in all areas.

There are also added benefits to this investment besides sustaining Airbus business over the next 20 to 30 years and growing profitably. Since Airbus has not developed a new aircraft in over 10 years, this is an opportunity to enhance and update its engineering and manufacturing process and technologies. Every new development program introduces new technologies and processes that can benefit both current and future programs. To stay competitive, Airbus has to invest in research and develop or acquire state of the art technology. By developing a new aircraft, the above need is satisfied.

See the competitive analysis summarized in Figure 4.2.

[49] "Current Market Outlook, 1999", Boeing Commercial Airplane Group, June 1999, pg. 46

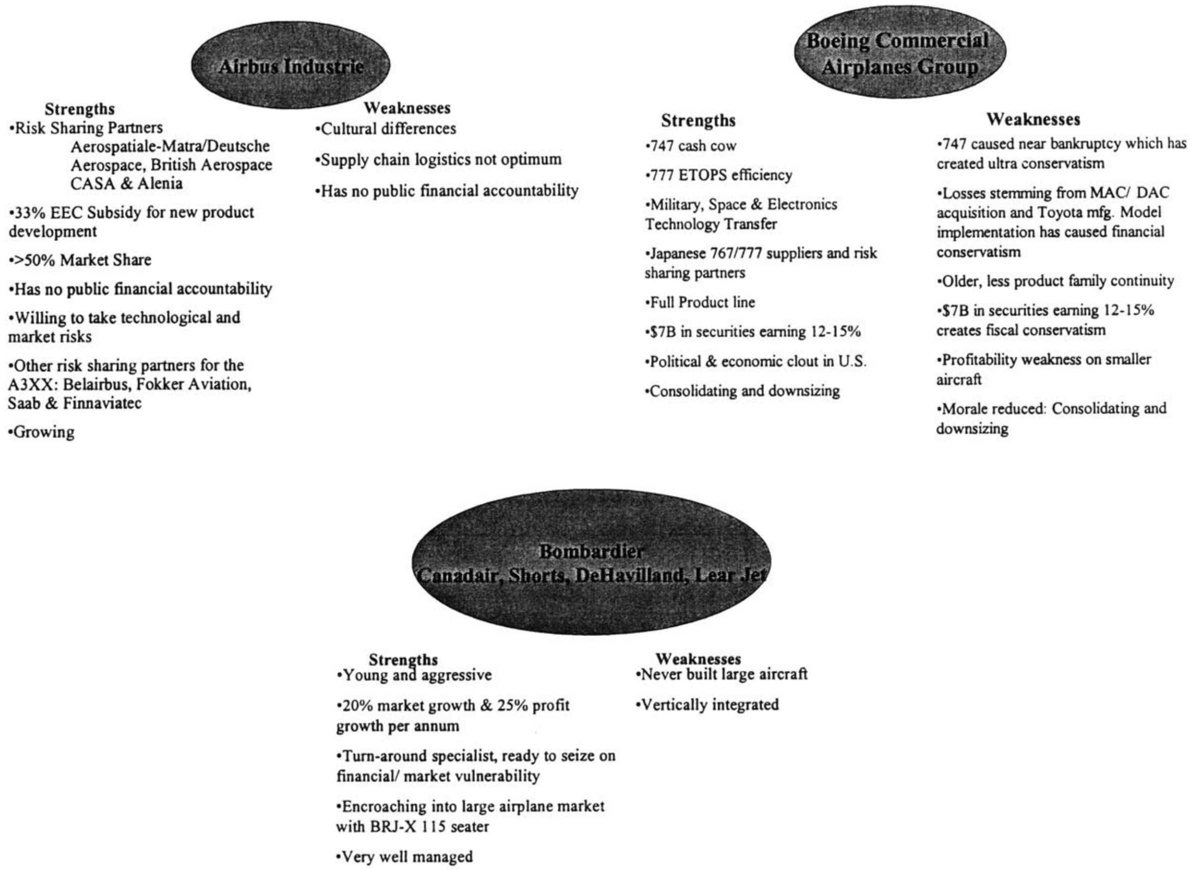


Figure 4.2 A Description of Competitor's Strengths, Weaknesses and Products

Aircraft Industry Forecast

Traffic Growth, Airlines and World Aircraft Fleet

Two separate market forecasts (Boeing and Airbus) project that the passenger traffic will grow between 4.8% and 4.9% over the next 20 years and that cargo traffic will grow between 6.4% and 5.7% over the same period of time[50,51]. Airline competition is intensifying and is causing consolidation among the airlines to achieve economies of scale in order to create operating efficiencies and to control the market better. Loyalty between airlines and the aircraft manufacturer seems to be diminishing. Currently there are over 13,000 aircraft in the world fleet[52]. From published forecasts there is, on average, a need for over 20,000[53] new aircraft over the next 20 years. Included in the aircraft market growth is the aging factor of the world aircraft fleet, which accounts for approximately 4,400 aircraft over the next 20 years[54]. There is a higher expected growth rate of 6.25% in the Asia-Pacific region for the next 20 years.

[50] "Current Market Outlook, 2000", Boeing Airplane Company, June 2000, http://www.boeing.com/commercial/cmo/4da01.html .
[51] "The Global Market Forecast", Airbus Industrie, 2000, http://www.airbus.com pg. 4, 25
[52] http://www.boeing.com/commercial/cmo/5apb3.html
[53] http://www.boeing.com/commercial/cmo/4wa06.html
[54] "Global Market Forecast, GMF99", Airbus Industrie, pg. 4

Boeing's Forecast and Assumptions

1. The airline industry has a profit cycle. The aircraft industry has a somewhat predictable cyclic nature. Based on this outlook Boeing thinks a retraction in production will occur, and this is happening at Boeing currently. However, Airbus is growing.
2. The deregulated airline market in Europe will create robust growth. This assumption predicts the cost of travel will reduce, and more passenger travel will occur in Europe. The distances covered in their market are short, which Boeing believes can be best served by smaller aircraft.
3. Oil prices over time are expected to remain stable after their rise in the last year. If this assumption were incorrect and oil prices rose rapidly as occurred in the '70s, then the cost of travel would rise in the airlines and passengers' ticket prices, and a significant decline in passenger travel would occur. Oil prices is one of the most important key indicators for profitability of airlines and robustness of the airline industry in general.
4. Emerging global airline alliances are building global brands and will support higher levels of service on high-density routes. The greater the competition the lower the ticket prices causing greater numbers of passengers to fly.
5. The gross domestic product (GDP) will continue to rise worldwide. It is believed that the rise in the GDP has a very significant correlation to increased passenger travel and cargo transport worldwide.
6. The Asian economic crisis seems to have bottomed out and is gradually improving. This will have an amelioratory effect on aircraft growth and a significant influence on the economic viability of the very large commercial transport for high-density city pairs traffic between the United States and Asia, and London and Asia.
7. Neither China nor Russia will have a significant influence on the aircraft industry. Although this is possible, both countries can be a competitive threat or a commercial opportunity as wildcards for the Boeing Corporation.
8. "The market for very large airplanes is small."
   The Boeing forecast is estimated to be 365 jets over the next 20 years in this very large airplane category, which has an estimated breakeven point of approximately 565 jets. If Boeing is wrong and the market is larger and Boeing does not produce its own very large transport, then beyond just creating a new market segment, Airbus with its large transport could possibly overtake the highly profitable 747 market segment as well.

The Airbus Global Market Forecast and Assumptions

1. "Worldwide demand for air transport will continue to grow strongly."
   If this assumption is wrong, Airbus may build overcapacity as well as a very large transport aircraft and force a disastrous economic outcome. On the other hand, if Airbus is accurate in this growth protection, compared to Boeing's conservatism, Airbus might leapfrog Boeing in the market with its aircraft fleet expansion.
2. "Dedicated freighters will assume a larger share of world air cargo traffic."
   This assumption is more justification for very large commercial transport.
3. The world's airports and air traffic management systems will not be able to handle the projected 95 percent increase in the number of passenger flights.
   Again, this is further justification for a very large transport aircraft.
4. There is an interesting system dynamics[55] model of the interrelationships among passenger fleet, freighter fleet, new, recycled, converted, and retired aircraft. This system dynamics model projects that 4,400 aircraft will be retired from active commercial service over the next 20 years. If this is true, then "new aircraft worth almost $1.3 trillion will be delivered."
5. "The composition of the world passenger fleet will also shift inexorably towards larger aircraft seating categories."

[55] This systems dynamics model was first created by the Pugh group (an outshoot of MIT) for Airbus.

It is projected by Airbus that the market share for greater than 400 seat airplanes, which was less than one percent in 1998, will expand to 18 percent by 2019.
Airbus assumptions are based on large aircraft service to high-density city pair routes between United States and Europe, Europe and Asia, and the United States and Asia, compared to Boeing's assertions that increased frequency of smaller sized aircraft will dominate the market.

6. It is Airbus' belief that increased comfort and aisle size will be demanded by the airlines and passengers. The Airbus very large transport aircraft is designed for greater passenger comfort.
7. Airbus projects that 1,235 very large aircraft with an average of 607 seats will be produced by 2019.
8. The belly/combi and dedicated freighter market segments will have substantial growth. Along with their forecast and assumptions, Airbus believes "large freighters will increasingly dominate world production." If these underlying assumptions and forecasts are wrong, then Airbus will be confronting an economic disaster, but if Airbus is correct, then they will enjoy an economic bonanza.

Future Scenarios Which Could Affect Forecasts; Conjectures About Their Impact

1. What if Bombardier continues its expansion beyond the regional jet market segments into the hundred plus seater commercial aircraft segments?
   The Bombardier Aircraft Group has been doing a superb job of corporate turnarounds for its relatively recently acquired companies. Bombardier started just ten years ago with its acquisition of Shorts Brothers in Belfast, Northern Ireland, and afterwards acquired Canadair, DeHavilland, and Lear Jet. There is a possibility that Bombardier could creep into the low end of the commercial airplane market similarly to how Canon entered the low-end copier market of the Xerox Corporation. The low-end commercial airplane market segment is notorious for its low or no profitability. However, a very efficient regional jet organization like Bombardier might successfully enter this low-end segment and begin the process to develop larger commercial transports. The effect might not be as great on Airbus, which so far is less accountable to normal shareholders, but creeping in could have a significant effect on the Boeing Commercial Airplanes Group, which might even concede the low or no profitable segments of this business due to shareholder pressures.
2. What if the SST becomes a viable commercial transport?
   If the technical, environmental and cost trades could be solved for the SST, it might create a new market segment which would compete directly with the very large commercial transport. The key to this possibility is that the passenger tickets must be very competitively priced, yet still provide acceptable returns to the airlines.
3. What if Russia and China independently or cooperatively produce competing aircraft to Airbus and Boeing?
   Finally, the Ilyushin 96 has been FAA/JAA certified. Over time more of the Russian aircraft with Western avionics and engines could become certified and enter the market. The Antonov 224 or 225, if they can be made economically, pass quality tests, and be FAA/JAA certified, could directly compete against the Airbus or Boeing very large commercial transports. The Antonov 124 is now being used by Volga-Dnepr, located in Ulyanovsk, Russia and Dublin, Ireland, for large cargo air transportation.
4. Boeing has been offering the C17 in a commercial version although there has been so far little enthusiasm for it. If the products and operating costs could be made attractive, the C17 could directly compete against a very large commercial transport alternative from Airbus.
5. The A400 is approaching a launch approval in Europe; however, this is a prop military transport which may not be at all acceptable to discerning passengers.
6. The C5 might be considered a competitive substitute to the very large commercial transport, but its operating cost, I suspect, would make it less of a threat.

7. It seems that Airbus and Boeing perceive the riskiness of the very large commercial transport differently. Airbus has risk sharing partners due to the structure of its ownership 33 percent of the required development investment would be contributed by the European Union, the consortium is driving to expand and dominate the commercial airplane market, and Airbus is not as constrained by outside shareholders. There is still no public profit and loss reporting accountability. On the other hand, Boeing although currently profitable, is still recovering from losses suffered during the acquisition of McDonnell Douglas and its less than successful attempt to incorporate JIT and other Toyota production scheduling and management systems. Boeing management is under heavy financial pressure by its chief financial officer and most particularly Boeing shareholders. In review of the Boeing balance sheet, it has in excess of $7 billion in cash or equivalents, so cash availability is not the issue. Instead, obtaining profitability to the expectations of outside shareholders is of current importance to the concern. Boeing does not appear to be in a position to "bet the Company." There seem to be symptoms similar to those described in the Innovator's Dilemma[56] (corporate inertia to making necessary changes for competitive sustainability) which might be preventing Boeing from exhibiting entrepreneurial instincts rather than its current product/market protectionist behavior. If this innovator's dilemma is actually occurring at Boeing, it could be overtaken by Airbus or others eventually.

Need for a New Aircraft

The key parameters determining a new aircraft development are contained in Figure 4.3 and the methodology for building its business case is shown in Figure 4.4. Airbus has not developed a completely new aircraft in more than ten years. Boeing has a near monopoly in the large (400+ seat) aircraft market and can use this unique position to subsidize its less profitable products to compete with Airbus. It is public knowledge that Boeing sells its low end aircraft at near break-even or below cost to win market share over Airbus. There has been an industrywide debate to justify the need for a very larger transport aircraft. The driving factors behind this yet uncertain need are traffic growth, increasing airspace and airport congestion, environmental concerns, and the economic risk versus benefit. Boeing, due to its financial responsibility to its shareholders, has decided not to develop a VLTA. Demand uncertainty is a major factor in Boeing's decision to discount the financial feasibility of such a program. According to Boeing, to cope with the strong traffic growth, the world fleet would need to add approximately 20,150 aircraft in all categories[50]. Airbus forecasts a need for 15,518 aircraft over the same period[51]. The substantial range in the number of aircraft needed is explained by the fact that Boeing believes that the growth capacity requirement will be met with new, smaller aircraft. Airbus, on the other hand, believes that the airspace is congested and that introducing new, smaller aircraft will further increase the congestion. The most efficient way to handle the capacity requirements and reduce airspace congestion would be to utilize larger aircraft to carry more passengers/cargo at a time.

[56] The Innovator's Dilemma, Clayton M. Christensen, Harvard Business School Press, June 1997.

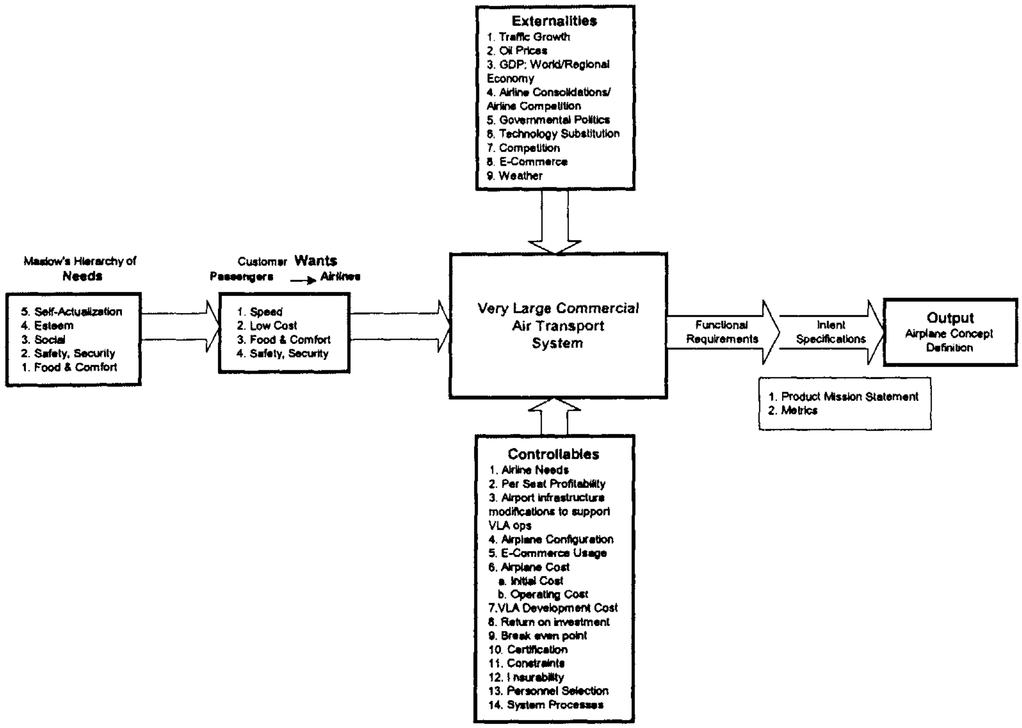


Figure 4.3 Key Parameters of a New Aircraft

Market Need

As mentioned earlier, the need and demand for a VLTA is uncertain. Both Boeing and Airbus agree that approximately 5% of the total aircraft needed will be in large aircraft categories (747 or larger)[50,51]. Based on the above numbers, this will account for between 930 – 1,208 large aircraft[50,51]. These numbers include the demand for a VLTA. It is not yet clear if the above numbers point to a VLTA or some larger version of the 747 class aircraft. Both forecasts see a potential for up to $1.38 trillion (in 1998 dollars) in revenue over the next 20 years. Boeing predicts that $180 billion will be generated by large aircraft market, whereas Airbus believes there is a potential for up to $263 billion in large aircraft market.[50,51]

Airbus should take a strategic approach to the VLTA program. That is, Airbus is not in a position to declare that a VLTA is not needed. Airbus should be ready to introduce a VLTA when it is actually needed before its competitor can get into the market. Getting into the market first and setting new standards in performance, comfort, safety, and reliability is thought to be crucial in capturing and retaining market share. Larger aircraft may also be preferred over smaller in the future due to the passenger popularity of hub-and-spoke networks and for reduction of airspace congestion. However, since the current demand is based on a 20 year forecast, it is believed that the VLTA market will not be completely realized for awhile. Additionally, most of the airports in the world would require significant modifications to serve a VLTA, which would delay the program's success and the time to break-even point.

Dense City-Pair Combined Population (millions) in 2014[57]

Tokyo – New York	50.0	Tokyo – Hong Kong	33.1
Tokyo – Los Angeles	37.3	London – New York	31.9
London – Tokyo	36.3	Tokyo – Singapore	30.1
Paris – Tokyo	35.9	Tokyo – Honolulu	28.0
Tokyo – Chicago	35.3	Frankfurt – Tokyo	27.8

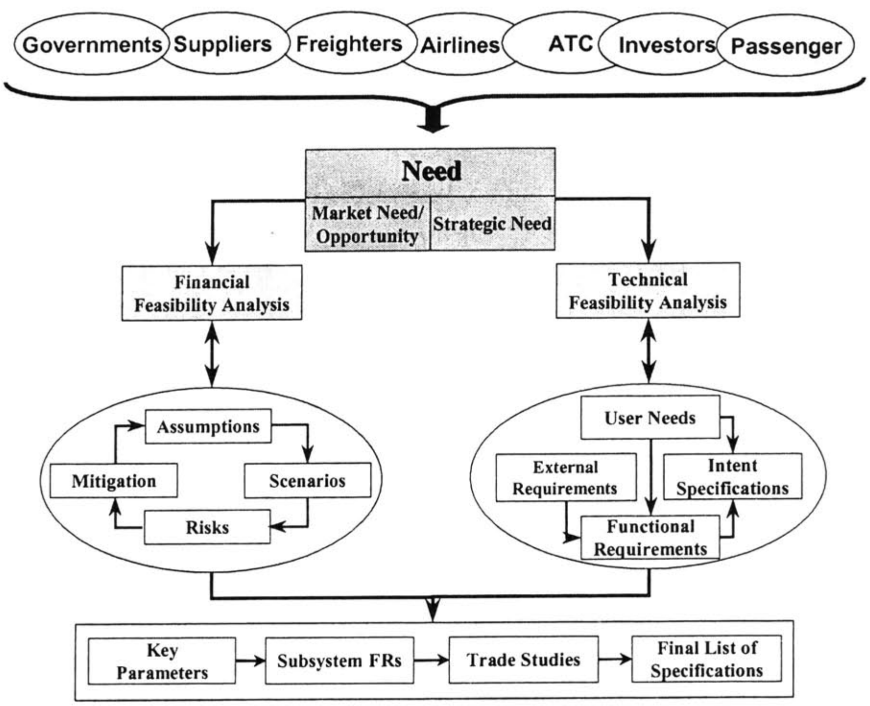


Figure 4.4 Business Case Analysis Methodology for Commercial Aircraft Impact on Gemcor

Based on the current state of the industry and from market demand analyses, it is concluded that there might be substantial financial risk involved in introducing a VLTA at present. However, market forecasts from Boeing and Airbus show that up to 5% of the new aircraft added to the world fleet will be aircraft of the 747 or larger.

The foregoing analysis suggests that the marketplace for commercial aircraft and the not analyzed military cargo aircraft in Europe is about to explode with business requirements necessitating new automatic fastening systems and fixturing. Gemcor and the competition will benefit greatly from this cyclical rapid market expansion and assembly system needs as shown in the VLTA market analysis for AFS in Figure 4.5. The question now becomes what should Gemcor do to capture the majority of the upcoming market. Possessing the desired technology, production capacity, organization, and financial structure is the answer. Alliances with strategic partners for geopolitical reasons and complementary assets in Europe and the U.S. also are necessary.

A planning concern is how Gemcor will handle the near term growth which may be 3 times its current capacity. The subsequent sections will discuss how one major benefit of the new product family, with its modularity, is improving product turnover by 50%, which effectively doubles the company's capacity.

[57] "The A3XX Market", A. Brown, V.P. Strategic Planning, Airbus Industrie, September 28, 1998.

Also, IT, MRP scheduling, and Drum-Buffer-Rope production enterprise system methods[58] that concentrate on constraint or bottleneck identification and buffer the bottlenecks to maximize their utilization and eliminate waste is expected to help make the production process LEAN. However, not all purchasers of new AFS's will buy the Escrst™, and the coupling with flexible fixturing will take more time and resources. Cash flow may be a constraint if progress payments do not sufficiently fund the orders. Gemcor has a good and expandable supply chain for components and fabrication and is globally qualifying system integrators to assist in portions of the assembly service/spare parts support. Another alternative being actively researched is that of an acquisition and/or a merger partner for obtaining the necessary skilled human resources, factory space capacity, and funding. The desire is to remain self-sufficient in what may very well be a rapidly changing and expanding market.

The Primary drivers for a big aircraft:

- Global and country by country GDP growth
- Traffic growth
- World oil prices and consequently jet fuel costs, the largest cost component of airlines
- Congestion at airports due to the growth
- Environmental concerns
- Economics, risk versus benefit

Customer Needs:

- Public
- Safety
- Environment
- Passengers
- Lowest fares
- On time
- Comfort
- Handling
- Airports
- Satisfy the demand
- Space efficiency
- Handling
- Neighborhood friendship
- ATC
- Satisfy the demand
- Flexibility
- Efficiency

[58] Necessary But Not Sufficient, E. Goldratt, The North River Press, 2000, P. 96. The Drum-Buffer-Rope production method delays the release of work orders according to their due dates, providing buffers in front of bottlenecks and use of the measure of inventory-dollar-days to control the level of inventory.

	Number of Automatic Fastening Systems	Ave. Price Each	Market Potential 2000 to 2002 (in $millions)
Wing AFS Systems			
Boeing			
Retrofit 747 WRS with Escrst for the 747X and XX	6	$ 3	$ 18
Retrofit 767 WRS	6	$ 3	$ 18
Retrofit 757 and 737 WRS	6	$ 3	$ 18
Retrofit 777 WRS	6	$ 3	$ 18
Airbus			
A3XX	7	$ 7.14	$ 50
A400	5	$ 4	$ 20
Fuselage Systems			
Boeing	7	$ 3	$ 21
Airbus			
Germany	8	$ 3.13	$ 25
France	6	$ 3	$ 18
Other	4	$ 3	$ 12
Bombardier Canadair	5	$ 2.5	$ 13
Bombardier Shorts	5	$ 2.5	$ 13
Other	3	$ 2.5	$ 8
Japan	4	$ 3	$ 12
Other Customers	6	$ 3	$ 18
Total			**$ 281**

Figure 4.5 The Market Potential 2000 to 2002 for Automatic Fastening Systems

Section 5

Competitor Analysis

The Competitive Space

The competition is composed of primarily Brotje Automation and Electro-Impact. Machine Dynamics is an infringer, which is being legally addressed, while occasionally Aerospace Precision Systems (APS) owned by Fairchild offers systems. The barriers of entry are high due to existing patents, knowledge of the industry, experience in automatic fastening of aerostructures, and lack of proven systems. The market niche will only support two to three competitors economically. The market share is shown in Figure 5.1. Machine Dynamics does not yet hold a market share.

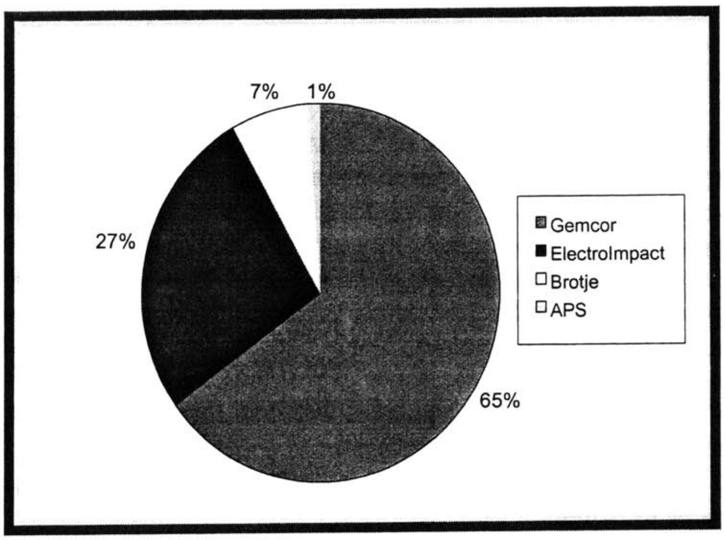


Figure 5.1 World Market Share Analysis for Aerospace Automatic Fastening Systems

Baxi and Brotje

In the early 1980's the Brotje family wished to diversify based on their automation core competencies in making radiator heaters for nearly the entire German market. They started Brotje Automation around 1990 the Brotje family seeing the consolations of European companies sold its business to Blue Circle. In December 1999 Blue Circle sold its heating group to Baxi in England in order to concentrate on the cement business. The heating group included Brotje Heating in northern Germany which owns Brotje Automation (BA). The automation company has no strategical fit with Baxi's portfolio and could be possibly subject to a spinoff or a consolidation strategy with Gemcor or others.

BA is physically separated by two to three miles from the Brotje heater production plant. BA's plant size is smaller compared to Gemcor's, but is wide open and well laid out for workflow. The original building is 12 years old and the new addition is 8 years. Regardless, because of German architecture, the building looks much older and is not very bright. The unattached office has two floors with administration on the first and engineering on the second. They are working at capacity in the office and maybe 65-70 percent capacity in the factory. They have sufficient capability for welding, painting, machining (manual machines, some with digital readouts), subassembly and final assembly, and testing in their plant. Heat-treating and overcapacity requirements are sent outside locally.

Other observations about the BA plant include:
–They use a bin type automatic rivet select system (ARS), copy of Gemcor's.
–Their fastening heads contain dual spindles and two tool changer systems.
–Interestingly, and something Gemcor should adopt, is the use of a 2 by 1 meter panel held at the work-line by two tall stands, which allows BA to do zero defect testing and reliability testing with limited X-Y motion and complete machine cycling for installation of fasteners in the panel.
–They use NSK or its equivalent for Y-axis rails, and they have copied Gemcor's low center of gravity positioner design.
–A closer look at their riveting heads shows that they are made of many parts and look too complicated and unreliable, and may be subject to operator bumping damage – too fragile and sensitive a design, not robust.
–They produce elaborate workframes with a complicated clamping system.
–BA recently replaced their financial manager.
–BA uses a Hewlett-Packard 2D CAD system.

Gerhard Holtmeier is the Managing Director of BA, transferring to the Bremen location of Brotje in 1994. Holtmeier has a mechanical engineering degree and came from the automotive industry in Stuttgart. The Brotje Automation organization is well managed yet underexploited for growth, particularly in the areas of fixturing and composites. It could expand into other assembly automation market segments, based on viewing several one of a kind machines they have designed over the years. Their business looked <u>currently</u> healthy with a backlog of approximately 25 million dollars. The German market fluctuates and contributes 30-60 percent per year whereas currently Gemcor has zero market share in Germany. With the strategy partially outlined below, Gemcor could expect 6-12 million dollars in revenue gain per year in Germany. The BA plant is leased and expires in 2001, so there is very little financing collateral other than projects' work in process and capital equipment.

Comparison of Gemcor to Brotje
A comparison of the companies show the following:
Gemcor
Pros:
– Brand name (Brotje says this is very valuable)
– Sales/marketing
– U.S. market
– Escrst™
– Vision for sustaining growth with positive EVA
– Product development
– Excellent motion control capability

Brotje Automation
Pros:
– Has built an automated body assembly tool (ABAT). Each ABAT selling for >$17 million but the market is only one every two years.
– Rugged mechanical designs (other than heads)
– Stable workforce
– Enjoys working in the aerospace industry
– Could diversify into different market segments of assembly automation
– Good fixturing capability, an underexploited opportunity
– Good production management

– Engineering driven
– Clean and tidy environment
– Good budget control
– Good change order management control
– European location
  – Located near Bremen airport (45 minutes)
  – Proximity to Europe, Russia and Asia
– Product development (underexploited opportunity)
– Heavy machining capability
– Welding, painting capability
– Organized work force in factory
– 200 total employees, 45 engineers (½ mechanical engineers and ½ electrical engineers)

Brotje Cons:
– High labor costs
– Rural location (15,000 population)
– No patents
– Expected future sales of ABAT are 1 or 2 in the next one to three years
– Rejection by the French and English markets
– No patent protection
– Design Issues
  - Complexity & robustness of heads
  - Crude pedestals

Other attributes:
Gemcor
– Controls and servos (electric and hydraulic)
– Product Development Center

Brotje Automation
– Heavy mechanical design capability
– Fixturing capability
– Creative thinking for assembly of aerostructures
– Product development capability using their creativity, particularly for the automotive assembly field where many of Brotje's engineers obtained their technical experience

One may note that motion controls were not previously mentioned for Brotje Automation. This is not to downgrade BA's capability, but Gemcor is more advanced in the programming and use of servo motion controls, but it is believed that Brotje is rapidly closing the technological gap. Despite the gap, an important question to ask is why Brotje is getting such large volumes of business.

1. BA and Gemcor each have other products
2. BA can more cost effectively service Europe, including Russia. Gemcor can more cost effectively service North America. (Transportation expense, travel expense, etc.)
3. BA has an excellent rapport with customers
4. BA has a solid, proven management team possessing a good planning system with apparent expertise in costing and project management execution
5. Established relationships and experience in automotive (Mercedes) and automation assembly industry segments. (Note – Low margin business, but even in good times a combined company may be able to utilize the combined excess capacity to enhance profitability.)
6. Apparently strong prospects for 2000

7. Very limited corporate support of BA by Brotje Heating and by Baxi except for tax, pension, legal and corporate finance matters
8. Clearly non-strategic business
9. Brotje pricing is 10% to 50% higher than Gemcor.

Customer Comments about Brotje

User: Boeing Wichita

User Perception:

GEMCOR machines are faster, more reliable; Brotje has frequent downtime, poor cycle time, long lead time for spares, user unfriendliness of machines as reported by operators and maintenance [machines are too complicated]

Major Brotje Downtime Issues

1. ARS
2. Tool Changer
3. Software

Downtime [Brotje] Over 10 Week Period

Gantries [riveting rings] = 27% unplanned

'C' frame types = 20%

Rivet Rate Brotje

Wichita: Expected = 8, Actual = 2 [Gantries]

Long Beach: No ROI on ABAT's purchased

Rivet Feed System

A. Cassettes are made by AHG [France]

B. Rivet Feed Downtime = 40%

Brotje Controller

CNC: Siemens

Language: German [creates obvious difficulties]

Perception of GEMCOR

A. Boeing Wichita

GEMCOR has reversed its trend of poor customer support. Brotje appear to be where GEMCOR was a few years ago in terms of the quality of their Customer Service Departments

B. Boeing Long Beach

Over the past 4 years the C-17 division has seen a large improvement in customer service which is attributed to a GEMCOR management change

Prices

Wichita - Gantry [Riveting Ring]: $17 Million

Wichita - 'C' frames: GEMCOR is typically 2/3 Brotje

Long Beach - Gantry = $60 Million

Electro-Impact

The Electro-Impact Company is located in Seattle, Washington, and has been in business since 1984. Their expertise is in servo controls and electromagnetics more detailed description of their technology can be found in Section 7. Electro-Impact has one important patent which covers a certain electromagnetic repulsion methodology used for automatic fastening.

Users of the Electro-Impact AFSs:

Boeing Long Beach

Boeing Renton

British Aerospace Chester

Equipment:	Automatic Vertical Spar Riveter [ASAT] Wing AFS for A320 and A340 wings
Rivet Rate:	4 rivets/minute
Pricing:	Similar to Gemcor

Aerospace Precision Systems [APS] owned by Fairchild

APS is a small AFS tooling and system rebuilder which has been foundering under Fairchild.

A. Harbour Pointe Observations

Field Technicians:	Qty = 6
Warranty:	New Machines = 3 years, Rebuilds = 1 year
Expected New Machine Life:	10 years
Rivet Feed Pricing:	10 Bowl ARS = $100,000
Controls:	Strictly Allen-Bradley [SLC & CNC]
Focus:	Low cost existing technology
Developmental Focus:	Ball screw driven toggle and ball screw upset

Offerings in violation of GEMCOR patents

1. Vibratory Insert
2. SPC
3. Roller Screw?
4. Clamshell Sealant
5. Vertical Riveter?

B. Raytheon Wichita Perception of APS

1. Vertical spar machine - 1 year late with design problems
2. Poor support [service & spares]

C. Pricing is 50% of Gemcor's pricing but their products are less robust and have reduced performance quality compared to Gemcor's.

International Tool Company (ITC)

A small division of ITC occasionally bids on small sized AFSs.

User: Raytheon Wichita

Price Structure

A. G300 type machine including 8 bowl ARS = $270,000
B. ITC version of GEMCOR G2000 = $2.0 million including 41 bowl ARS
C. Program Methodology: Digitizing only
D. Pricing is 50% of Gemcor's pricing but their products are less robust and have reduced performance quality compared to Gemcor's.

	ELECTROIMPACT	BROTJE	GEMCOR
Profile	Hi-Tech	German Engineering & Quality	-Old Reliable/Durable
Focus	CNC Spars & Wing Riveter	Large CNC Rings & 'C' Frames	CNC Wing Panel & Fuselage Riveters
Process	LVEMR	Hydraulic Squeeze	-Hydraulic Squeeze/Squeeze III -Roller Screw
Technology	-Vertical Riveting	-Horizontal or Ring Riveting	-Horizontal Riveting
Spindle	-20,000 RPM Electric Spindle	-24,000 Electric/10,000 Hydraulic	-12,000 Hydraulic, 20,000 RPM electric
Transfer	-Flat Electric Linear Motion	-Hydraulic Cylinder	-Servo Hydraulic Cylinder, Rollerscrew, rotary*
Head Positions	-6	-4-5	-6-8*
Hole Probes	-Mechanical -Low Cost	-	-Capacitance-high cost, Mechanical, low cost
Pressure Foot	-Fixed	-Fixed	-Floating Workline
Panel Protection	-No	-No	-Yes
Servo Buck	-Alternate Means	-No	-Yes
Dual Acting Clamp	-No	-No	-Yes
Slug Rivet Rate	-6/minute	-6/minute	-9/minute
Fuselage Rivet Rate	-	-2-7/minute	-15/minute
Panel Sensor	-Probe through P.F.	-No	-Servo Pressure Foot
Normality Sensor	-Ultrasonic	-Laser	-Reluctance
Controls	-A/B, Fanuc	-Siemens	-A/B, Fanuc, NUM, Delta-Tau
HMI	-No	-No	-Yes
Rivet Feed	-Bin/Cassette	-Bin/Cassette	-Bin/Bowl/Cassette
Collar Swage Tool	-E/I	-Huck	-Huck
Fixture, [Flexible]	50% of Business	20% of Business	0% Business
System Uptime	90%+	70%	95-98%
Staff	60 Engineers working as Product Teams	200	250
Other Products	-Handguns -Manlifts -AFDE Floor Drills -Flex -Fixturing		Forming Rolls

Table 5-1 Comparison of Competition

Strategical Considerations

German ⇒ European Marketing Channel

Gemcor has formed an alliance with a controls application and service company, ProCtech, located near Frankfurt, and the German Board member for Gemcor. The company mapped a low-risk strategy to start ProCtech as a sales representative of Gemcor in Germany only. Gemcor's Director of Sales along with the Gemcor Board Director and a ProCtech sales engineer visited the German DASA customers. Gemcor's main competition is located in Germany so this strategy will serve as a frontal attack on the primary source of competition.

The brand name, GEMCOR, will be emphasized, and a Gmbh subsidiary has been created which is owned by both parties. The new corporation will sell and produce modules of the Escrst™ product line, provide working capital, personnel and manage assigned work locally. Merging ProCtech in total with Gemcor has been discussed, as well as incorporating it in the Netherlands or Belgium because of low taxes. The ProCtech -Gemcor subsidiary will have sales, production responsibility, and service and spares for Germany, expanding over time to all Europe.

France

For geopolitical advantage in capturing the highest market share, Gemcor is negotiating with two strategic alliance partners in France for sales representation, service and spare parts. It is also perhaps that this alliance partner will fabricate non-strategic components of Gemcor systems for the French and possibly Spanish markets.

Fixturing

As can be seen in the comparison chart, Gemcor does not produce fixtures (except for workframes) as is being done by the competition. To strengthen this weakness and be able to provide complete turnkey system packages to customers, Gemcor formed an alliance with the fixturing division of Pacific Aerospace and Electronics (PA&E). This is a publicly held company located in the State of Washington, with an annual volume of $110 million. PA&E has good relations with Boeing but little international experience for a competitive advantage, their fixturing systems are now being architecturally coupled for best assembly throughput using Catia-Deneb simulation software to study design alternatives, to make presentations to customers, and to time the complete assembly sequences in order to verify conformance to production rate requirements.

Escrst™ Market Introduction with Respect to Competition

While strategizing the market introduction for Escrst™, Gemcor considered creating a weak competitor by patent licensing in order to grow the market and become the dominant player. One competitor is already trying to copy Escrst™, which provides sufficient support for the new paradigm. The market niche certainly will not support several competitors. Even though the new product line introduction is expected to follow the typical S-curve pattern, the competition may be at a technological disadvantage for the upcoming surge of new airplane launches and the accompanying AFS and fixturing requirements, possibly resulting in significantly losses of market share.

There are a few strategic directions Gemcor can pursue to be in a strong market position with the commercial airframe automatic fastening niche. Gemcor could: merge with or acquire Brotje Automation, combine with a machine fixturing company (beyond an alliance) to provide a "complete package" solution to customers, stay independent and rely on the advanced product line and alliances with fixturing companies and geographical build partners regionally worldwide to capture the market. Part of the strategy development and expectations is opportunistic, meaning that Gemcor will follow in parallel different strategies to find the best strategy going forward. Although such strategies deepen Gemcor's service to the current market niche for the intermediate term, it does not expand the company into other strategic markets. Section 7 and 8 discuss expansionary directions.

Section 6

Description of Automatic Fastening Systems

The Drivmatic® Process

Prior to the development of the Drivmatic® process, aircraft panels were machined and put into fixtures to establish the geometric positioning of their panels and subparts (i.e. stringers). Since this was during World War II, women drilled the holes, and then the panels were taken out of the fixtures and the holes deburred to eliminate stress risers and potential crack and fracture failures during the airplane's cycles (most of the impact load during the cycle is on takeoff and landing). The panels and subparts were next reloaded back into the fixture, the women would manually put the rivets in the predrilled holes, and then vibratory guns were used to vibrate the rivet head from one side of the panel and bucktail from the other side. This is the standard manual riveting process which is still in use today.

In 1948 Gemcor invented and developed the Drivmatic® process, which clamps the panels and stringers together tightly, then automatically drills a burr-free hole, inserts the fastener, and squeezes (upsets) the rivet. There was originally considerable argument in the aircraft industry that the Drivmatic® process resulted in inferior quality compared to the manual process until the airframe manufacturers did comparative tests and found just the opposite. Because of the consistency of the automation vs. manual process, the strength and fatigue life of the joint improved dramatically – automatically riveted joints were four times stronger and had four times greater fatigue life than manually riveted joints. The diffusion of this technology was slow but made steady progress. Today all commercial aircraft wings produced by the dominant aircraft producers use Gemcor's special slug Drivmatic® riveting process, and approximately 70 percent of the remaining airframe structure is assembled using the standard Drivmatic® process. Some variations of the Drivmatic© cycle based on fastener types are shown in Figure 6.1.

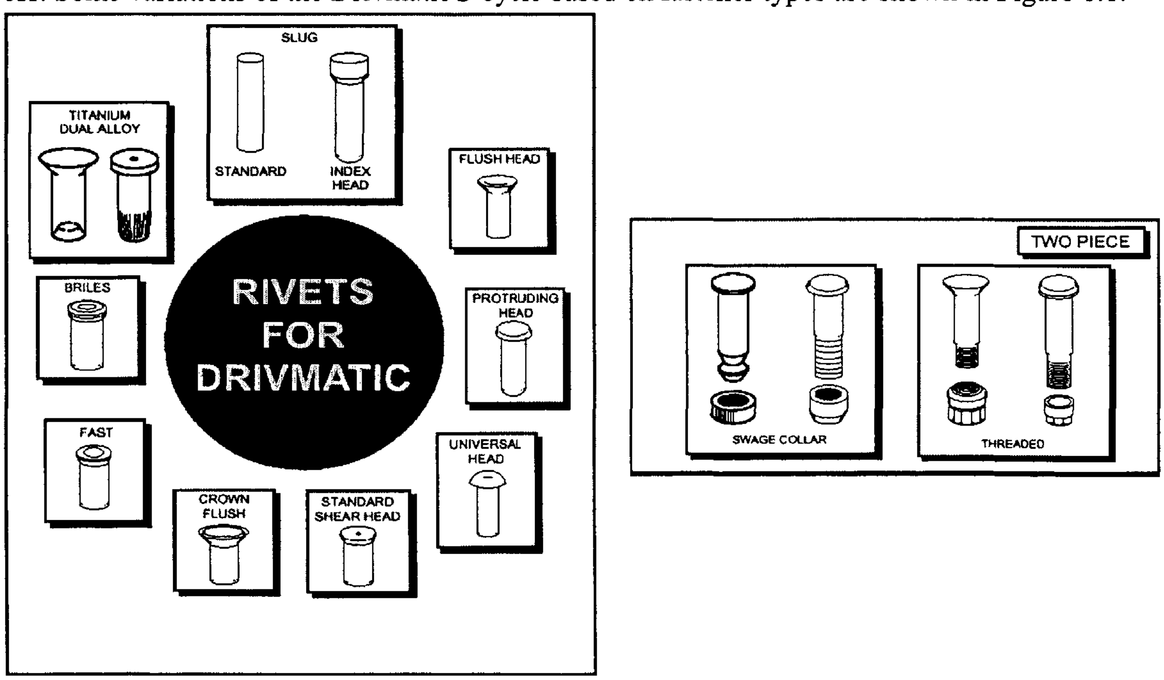


Figure 6.1 Typical Fastener Geometries Installed Automatically by the AFS

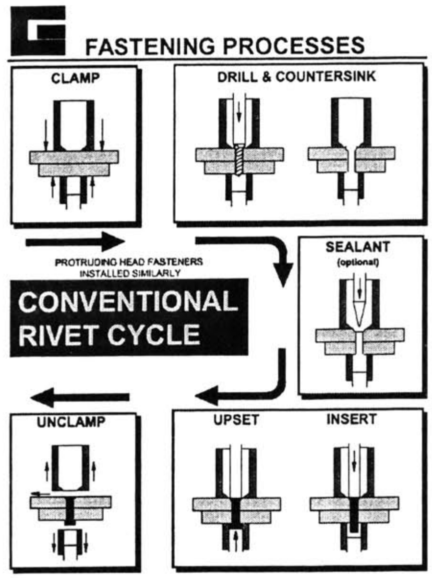


Figure 6.2 The Basic Automatic Fastening Cycle

In Figure 6.2 the basic cycle may have a sealant applicator. This optional subsystem is used for precise application of sealant to the hole, the countersink, the shank of the fastener, or the countersink of the fastener. The sealant protects the metals from corrosive galvanic reaction, salt corrosion, fuel leaks, and moisture traps, as well as providing some bonding, sound dampening, and fatigue life enhancement.

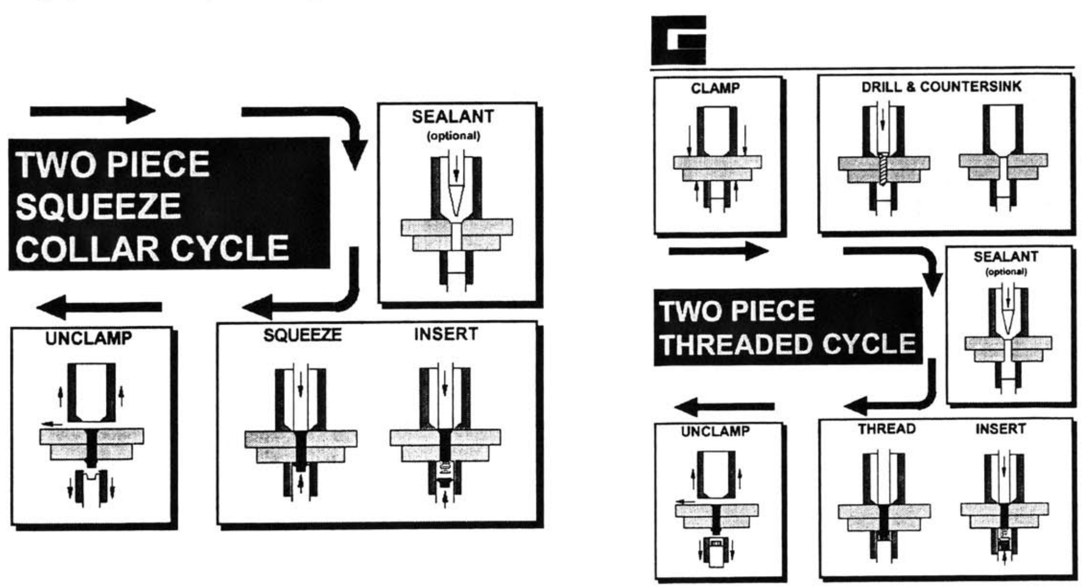


Figure 6.3 The Two Piece Fastener Automatic Fastening Cycle

Two piece fasteners require special considerations shown in Figure 6.3. Their collars or nuts must be separately stored and pneumatically fed, then installed on the pin. The nut drivers can measure and control angularity, revolutions, and applied torque. Their reliability is good, but robustness improvements would be desirable to customers. Collars are easier to install since they can be made symmetrically and only require a relatively simple cold work swaging stroke under servo force control to properly seat the collar on the concentric threads of the pin.

The slug (Figure 6.4) was invented by Gemcor in the late 1960's and patented in the early 1970's. It is the embodiment of all the current teachings in design for leanness. Its invention caused the elimination of fuel blatters in wings. Also, use of slugs significantly reduced the number of heavy and costly two piece fasteners which require sealant applied. Wings especially could now be made lighter and stronger with assured fuel tight joints without the need for sealant. Furthermore, the slug necessitated automatic installation because of the high squeeze forces required. The physics of the fastener is well covered in a separate journal article[59]. The slug fastener is much less expensive than two piece fasteners for highly stressed structural zones of the aircraft. This is a very interesting historical example of a technological change which provided a total systemic change in the manner aircraft were designed and manufactured.

In the 1980's customers wished to control assembly tolerances more closely and requested a modification to the slug process which reduced the movement of the panel during upset to .005". This new patented cycle, shown in Figure 6.5, is called the squeeze-squeeze process since force and position servo control are used to precisely cold form the slug from both sides of the fastener. For fuselage and wings, the current practice is to place panels, support members, and other parts such as forgings in a fixture, tack them with 5% or fewer permanent fasteners or Clecos, by crane move the inner workframe out of the fixture to the automatic fastening system with the panel clamped, and load and auto clamp it to the outer workframe for automatic positioning in the AFS. More flexibility is being provided on the workframes to accommodate families of parts with similar geometry which vary mainly by size. The cycle of the squeeze-squeeze is complex and is depicted in the object process diagram, Figure 6.6. Taking a larger view of the system within which an AFS operates, two object process diagrams are provided in Figures 6.7 and 6.8.

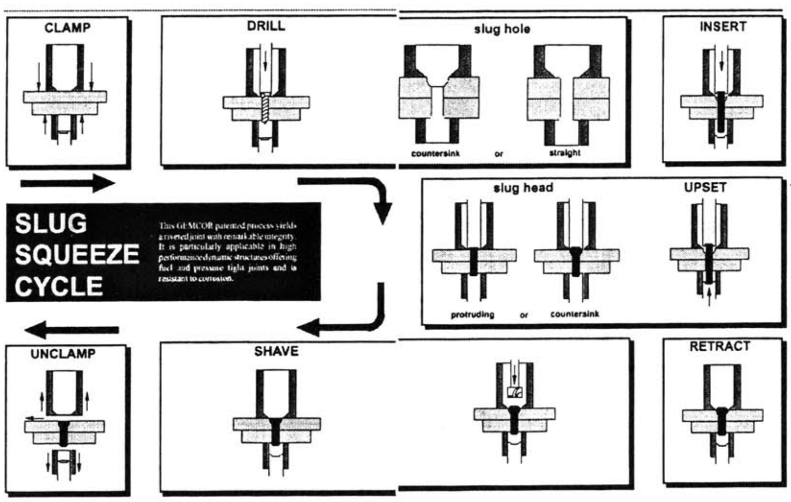


Figure 6.4 The Slug Fastener Automatic Fastening Cycle

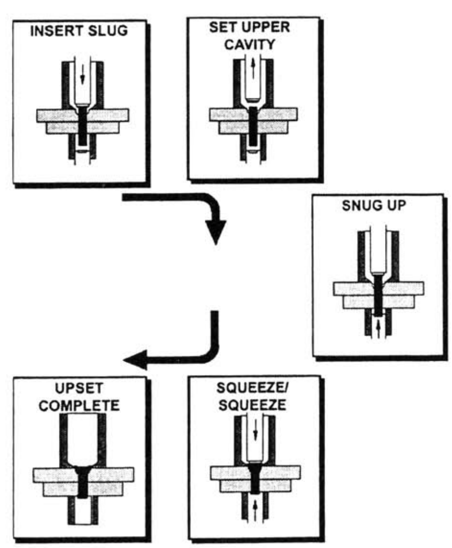


Figure 6.5 The Squeeze-Squeeze Slug Fastener Automatic Fastening Cycle

[59] "Fuel Tight Fastening by Automatic Machine," T. Speller and J. Randolph, Aircraft Engineering, February 1972.

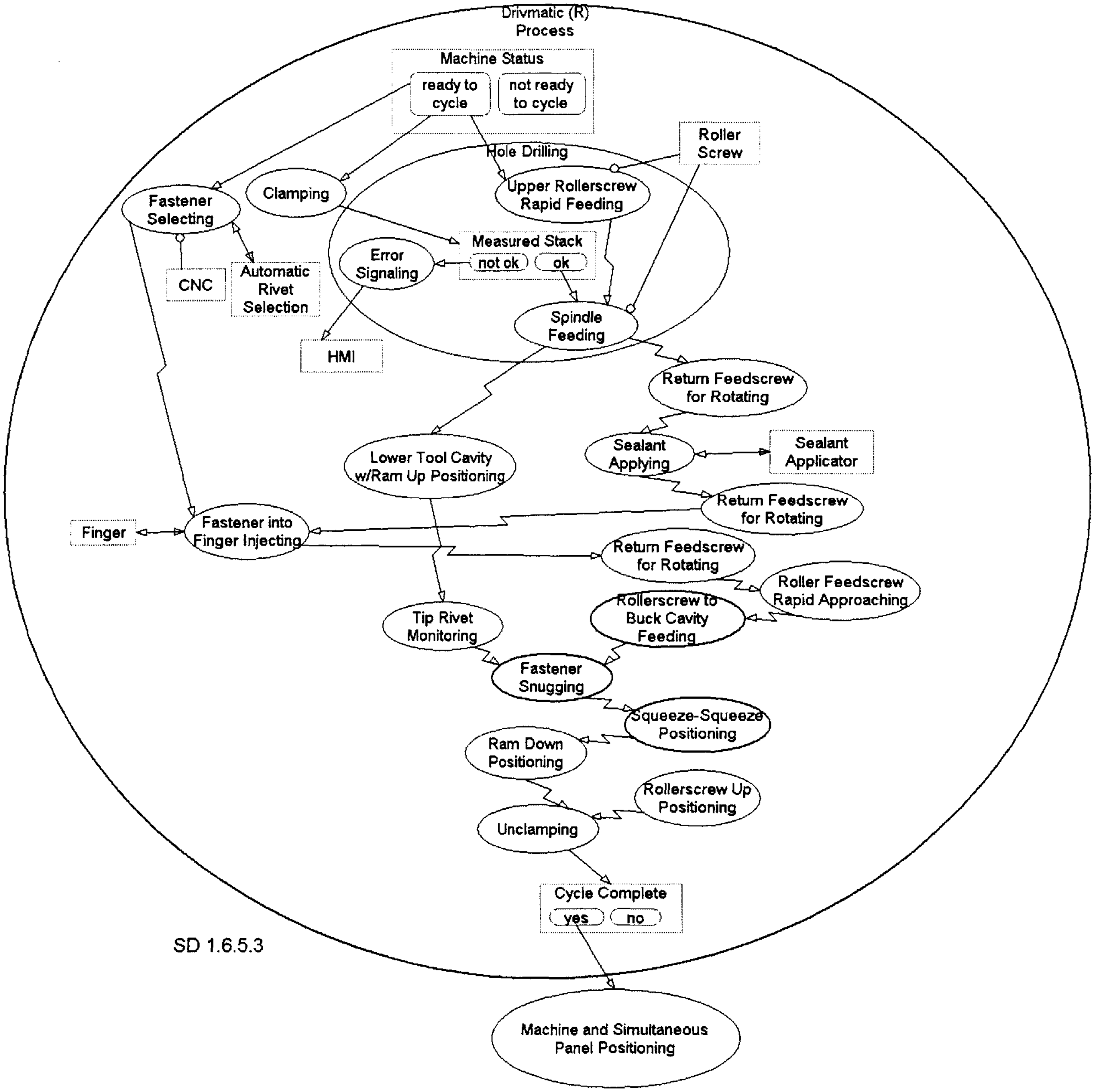


Figure 6.6 The Squeeze-Squeeze Slug Fastener Automatic Fastening Cycle Object Process Diagram

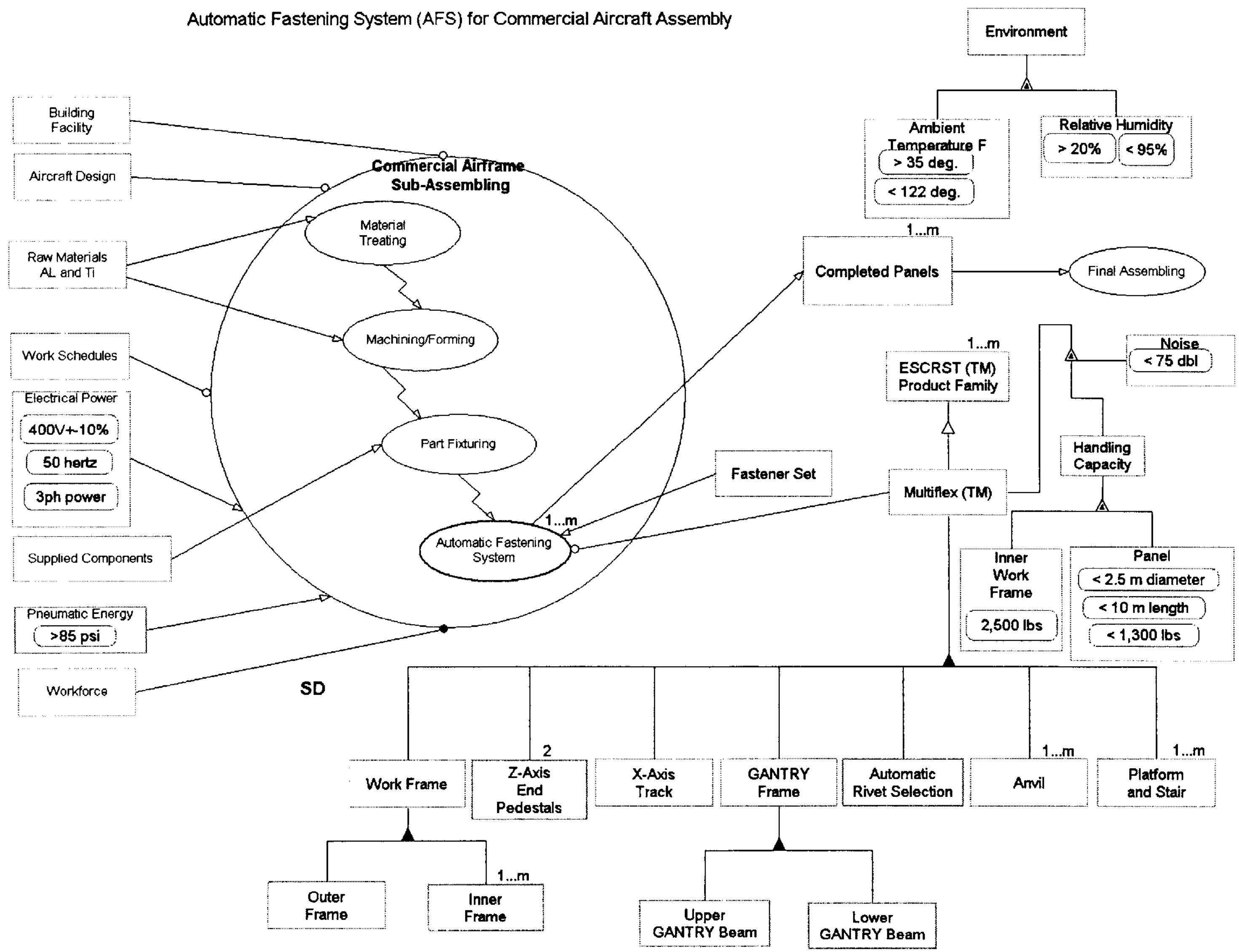


Figure 6.7 The Object Process Diagram of the Automatic Fastening System (AFS) for Commercial Aircraft Assembly

Figure 6.8 Object Process Diagram of the Multiflex™ Automatic Fastening System

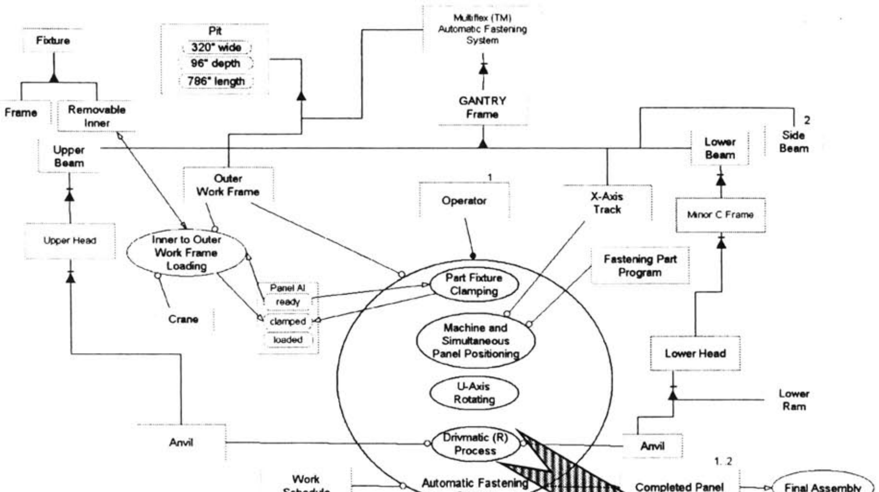
- The Pit exhibits 320" wide, 96" depth and 786" length and consists of the Multiflex ™.
- The Multiflex ™ partially consists of GANTRY Frame which consists of the Upper Beam, Lower Beam and two Side Beam.
- The Automatic Fastening System consists of Part Fixture Clamping, Machine and Simultaneous Panel Positioning, U-Axis Rotating and the Drivmatic® Process.
- The Outer Work Frame, Work Schedule, Control and Operator enable the Automatic Fastening System.
- The Automatic Fastening System outputs one or two Completed Panel.
- Completed Panel one to many input to Final Assembling.
- The Fixture consists of the Frame and the Removable Inner.
- The Crane moves the Removable Inner and positions it into the Work Frame Outer.
- Part Clamping receives the Inner Work Frame and indicates a clamped condition followed by a loaded condition.
- The Machine and Simultaneous Panel Positioning is enabled by the X-Axis Track and the Fastening Part Program.
- The Drivmatic® Process is enabled by the Upper Head Anvil and Lower Head Anvil.
- The Control consists of the Hardware and the Software.

The OPL

Object Process Language

The OPD

Object Process Diagram

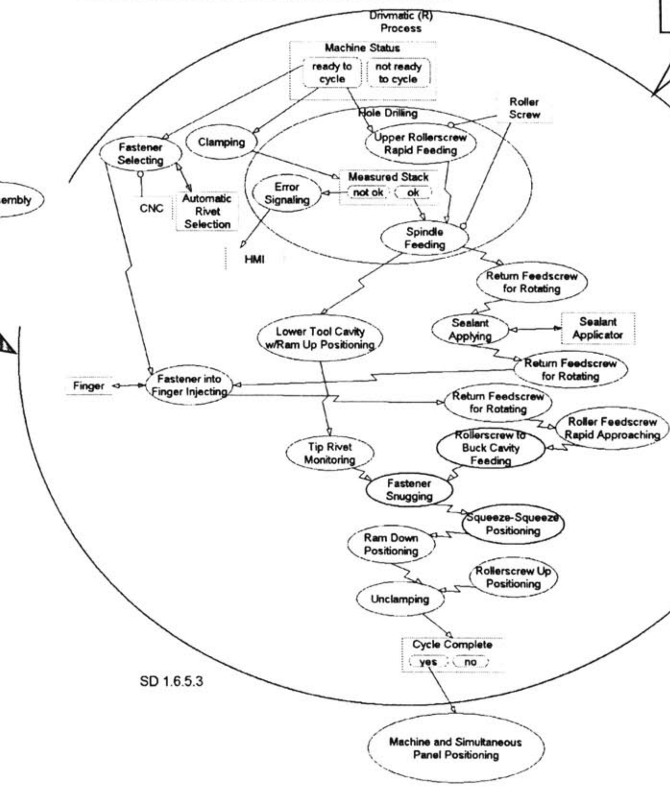


SD4 Drivmatic® Process Zoom In

- The Drivmatic® Process consists of Machine Status, Fastener Selecting, Clamping, Hole Drilling, Roller Screw, CNC, Automatic Rivet Selection, HMI, Lower Tool Cavity w/Ram Up Positioning, Return Feedscrew for Rotating, Sealant Applying, Sealant Applicator, Finger, Fastener into Finger Injecting, Roller Feedscrew Rapid Approaching, Rollerscrew to Buck Cavity Feeding, Tip Rivet Monitoring, Fastener Snugging, Squeeze-Squeeze Positioning, Ram Down Positioning, Rollerscrew Up Positioning, Unclamping, and Cycle Complete.
- The Drivmatic® Process upon Cycle Complete yes sends a signal to Machine and Simultaneous Panel Positioning.
- The Machine Status is ready to cycle or not ready to cycle.
- If the Machine Status is ready to cycle, then Fastener Selecting, Clamping, and Upper Rollerscrew Rapid Feeding.
- The CNC enables Fastener Selecting and the Automatic Rivet Selection effects Fastener Selecting.
- The Roller Screw enables Upper Rollerscrew Rapid Feeding and Spindle Feeding.
- Hole Drilling consists of Upper Rollerscrew Rapid Feeding, Measured Stack, Error Signaling, and Spindle Feeding.
- The Measured Stack receives input from Clamping and if ok, then Spindle Feeding, if not ok, then Error Signaling to the HMI.
- Fastener Selecting activates the Fastener into Finger Injecting.
- Fastener into Finger Injecting effects Finger.
- Spindle Feeding completion causes Lower Tool Cavity w/Ram Up Positioning.
- Spindle Feeding completion causes Return Feedscrew for Rotating.
- Return Feedscrew for Rotating to Sealant Position and commences Sealant Applying.
- The Sealant Applicator effectuates Sealant Applying.
- Sealant Applying completion signals the Return Feedscrew for Rotating to the Upper Anvil for Fastener into Finger Injecting.
- Previously Fastener Selecting provides a fastener into the Finger for Fastener into Finger Injecting.
- During the Fastener into Finger Injecting there is Tip Rivet Monitoring.
- The Lower Tool Cavity w/Ram Up Positioning effects the Tip Rivet Monitoring.
- Fastener into Finger Injecting completion initiates the Return Feedscrew for Rotating and then initiates Roller Feedscrew for Rapid Approaching.
- The Roller Feedscrew for Rapid Approaching initiates Rollerscrew to Buck Cavity Feeding.
- If no Tip Rivet condition then Rollerscrew to Buck Cavity completion initiates Fastener Snugging.
- Fastener Snugging completion initiates Squeeze-Squeeze Positioning.
- Squeeze-Squeeze completion initiates Ram Down Positioning.
- Ram Down Positioning completion initiates Rollerscrew Up Positioning and Unclamping.

Control
Hardware
Software

Top Level System Diagram



Section 7

Functional Derivation of an Escrst™ Automatic Fastening System

Creation and Evolution of a New Product Family of Automatic Fastening Systems for Aerostructures

This section provides a description highlighting the creation and evolution of a new product family for Gemcor, relating this product development to the lessons learned in Systems Architecture. (See Exhibit 7-1) The product family described herein encompasses and consolidates many years of special automatic fastening machinery production, which was too often managed on an independent project basis. There were several driving forces upstream influencing the idea of creating a product family. Gemcor's corporate strategy requires that the aerostructures assembly subsidiary produces a positive economic value added. The hurdle for creating economic value was set at 15 percent, which is the company's cost of capital. In order to attain this level of profitability, product margins had to drastically increase. Further, the corporate strategy requires diversification to mitigate the oscillatory market behavior in the commercial aircraft production. After investigating mergers and acquisitions, it was determined that the lower risk and higher probability of market and financial success in diversification would be through product development since more product families can be developed at lower cost in shorter time with leading-edge high customer valued technology, rather than following the route of a few very high cost and complex merger/ acquisition possibilities.[60] This first product family development is to serve as a model for creating other product/market families with a quick time to market and high probability of market and financial success. Another upstream driving force was competition, which gradually had been taking greater market share over the past 15 years. The force of technological change also drove or created the pressure to change the pattern of sales, product design, and production for the company. The onset and impact of another industry down cycle served as the impetus to such change.

The enterprise goal of creating a sustaining positive EVA was decided. One of the first considerations in attaining the goal was the upstream and downstream influencers on the product development endeavor. Some of the influencers are listed below, and Figure 7.1 presents a more complete tree of influences and goals for the entire enterprise, and the product to be development served as the guide for understanding and incorporating the totality of influences.

Upstream Influencers:

- Regulation and environmental considerations
  - Low Noise (65 dba)
  - No petrochemicals used
  - Meets U.S. and European CE Codes
- Corporate strategy
  - Satisfies the mission, core competencies and technology strategy of the corporation
  - Satisfies financial requirements of corporation
- Market need, strategy and competition
  - Satisfies Voice-of-Customer (VOC)
  - Is better, faster, more flexible and lower cost than the competition
- Technology
  - Satisfies marketing strategy

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[60] Usually the opposite argument is heard; however, the history of mergers and acquisitions indicates the majority of them reduce total enterprise value due to the complexities on bringing different cultures together and competing or disassociated technologies which do not create alignment of mission and purpose to the organization. The theory upon which the preference of product development over mergers and acquisitions is discussed in Section 9, "A Model of Sustaining Corporate Growth for Gemcor."

Exhibit 7-1 System Architecture

Need ⇒ Goal ⇒ Function ⇒ Creativity ⇒ Concept ⇒ Form

	Why?	What?	What?	How?	Creativity	Where?	Where?	When?	When	Who?	Who
Prof. Crawley[61]	Need Purpose	Product Goal Performance	Process Goal	Product Function Behavior	The Creative Process	Product Form Structure	Process Form	Product Timing Action	Process Timing	Product Operator User	Process Operator User
Gemcor Application	-Survival -Competitive Advantage +EVA -Diversification to reduce oscillations -Improve airframe fatigue life and strength -Satisfy the customers	-25% faster than competition Lower cost than competition -Simpler architecture -Ease of maintenance -More user friendly -Ease & comprehensiveness of Process Controls -Increased Robustness, 95% Uptime	Used QFD, House of Quality and VOC to determine customer wants, Customer upfront involvement in determining requirements and conceptual approach, see Exhibit 7-2, for holistic customer supply chain view -Ease & comprehensiveness of Process Controls -Increased Robustness, 95% Uptime	Behavioral/ Functional -Drivmatic© process of automatically positioning to fastening location, clamping the part, drilling a burr free hole, applying sealant, inserting the fastener, upsetting the fastener -Intent Specifications were written	Use of Learning Forum composed of a very experienced Cross Functional Team (5 member), Significant psychological pressure and tension existed to create productively	Concept, form - Escrst™ core technology coupled with rotary turret head as a product platform -See Exhibits 7-8 & 7-9 through 7-14 for different architectural depictions -Layered Software Architecture	Heuristics, Cost, FMEA, DFMA, CAD/CAE/ CAM/PIM, Simulation studies	Functional behavioral diagrams were used	Matrix organization, MRP, JIT, IT Workflow systems, MSProject management	User -HMI user friendly operating screens	- HMI user friendly maintenance and engineering process control screens

[61] Ed Crawley, 16.882 System Architecture Course, Fall 1999

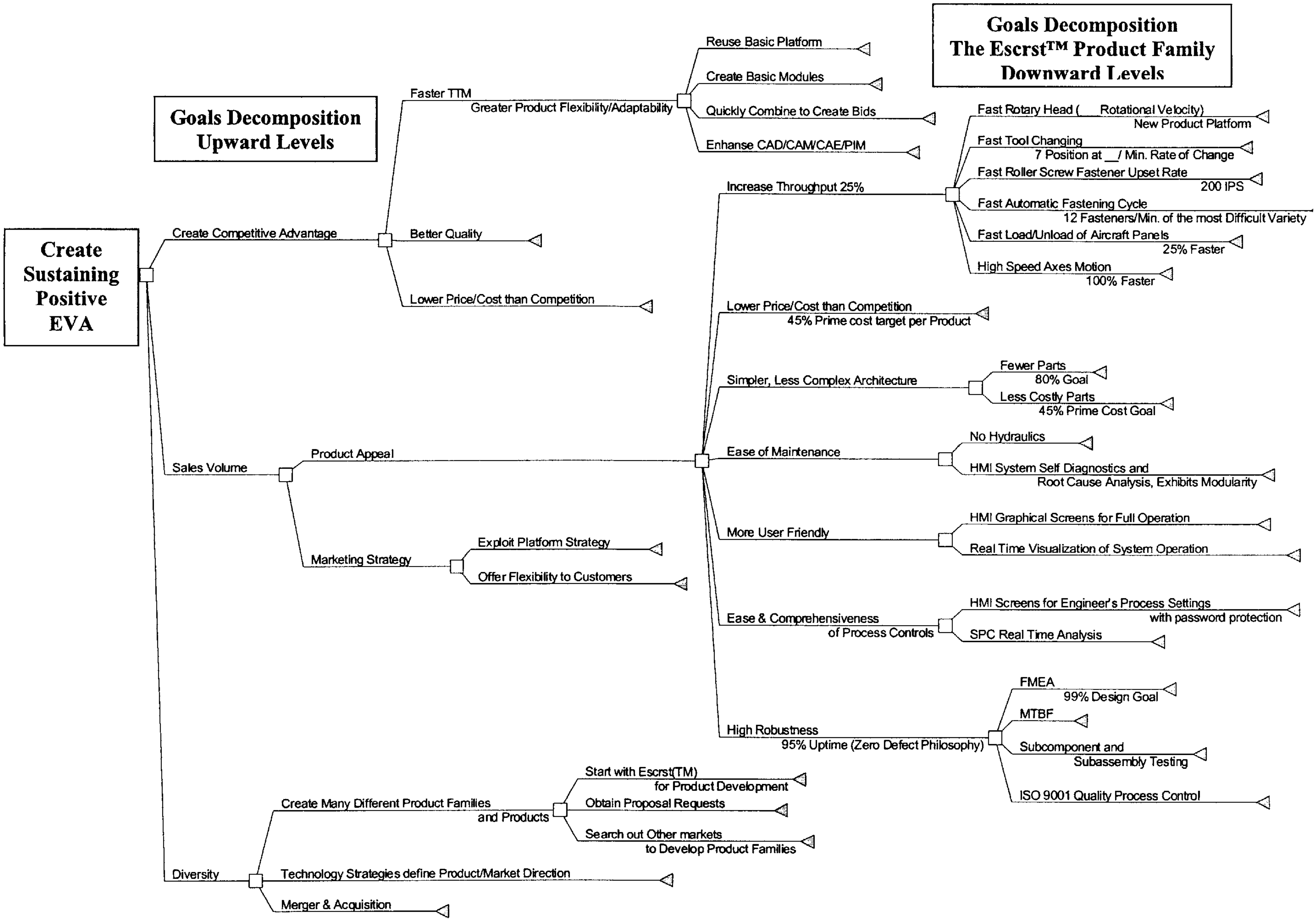

Figure 7.1 Goals Decomposition, Gemcor Corporate (Higher Level) and The Escrst™ Product Family (Lower Level)

Exhibit 7-2 Customer Supply Chain and System Architecture Needs Hierarchy

Customer Need: <u>To TRAVEL</u>

Public Need:
–To travel from one place to another as fast, comfortably, cost effectively, safely and as easily as possible

Safety and Efficiency
The traditional drivers to aircraft design are safety and efficiency. Safety translates to structural strength, fatigue life, functional reliability and extremely low probability of catastrophic failure. Aircraft efficiency relates to cost of operation, which is dependent upon operating costs (crew personnel and fuel costs) and maintenance costs. Fuel cost is reduced by lighter aircraft and reduced surface drag.

Airlines' Purpose:
–Fly airplanes to satisfy the public needs expressed above

Airlines Needs:

Airplanes
–Low cost to purchase, operate and maintain with fast, easily accessible spare parts at reasonable prices
–Easy to fly
–Easy to train pilots
–Comfortable aircraft that people want to fly

Pilots
Service personnel (trained)
Cabin crew
Airports
Fuel

Aircraft Manufacturers' Purpose:
–To satisfy the airlines' needs

Aircraft Manufacturers' Needs:
–Aircraft designs which meet the needs of the airlines
–Manufacturing methods and technologies to build the aircraft to the exacting requirements of the aircraft design
–Skilled labor
–Machinery and manufacturing systems
–Service and spare parts

Suppliers' Purpose:
–To satisfy the aircraft manufacturers' needs

Suppliers' Needs:
–Designs which meet the needs of the aircraft manufacturers
–Manufacturing methods and technologies to build the systems, equipment and components to the exacting requirements of the aircraft design
–Skilled labor
–Machinery and manufacturing systems
–Service and spare parts

Suppliers' (sub-tier, components and raw materials) Purpose:
–To satisfy the tier 1 suppliers' needs
-Utilizes the best closed loop servo controls technologies and human machine interface systems

Operations Strategy
-Uses DFMA to reduce parts by 80%
-Has an order to delivery cycle time of 50% of previous products
-Has Zero Defects (95% reliability, uptime)
-Processes

-Required adherence to corporate processes established for product development and
-ISO9001

Downstream Influencers: (All functions were represented as members of the Integrated Product Team in concept and design creation):

- -Manufacturing
- -Service
  - -Remote computer linkage for system health monitoring and control
    - -Timing
    - -Operator
    - -Training
- -Maintenance
- -Automatic Fastening System

The machinery for the commercial aircraft assembly niche historically has been based upon hydraulics and numerical controls. The system architectures for these different point designs[62] have resulted in many parts, high complexity, high production cost, bottom-up design, two-dimensional CAD design, and final reliability testing that was left up to the customer to do. One customer, Boeing, developed an electromagnetic repulsion process which was intended to provide equal and opposite reaction forces to permit a much lighter structural automatic fastening system at lower cost and higher flexibility for accessing all fastening areas in a commercial aircraft structure. Boeing's manufacturing research and development department designed and built an electromagnetic system for the 767 wing spar assembly. There was great difficulty in achieving consistency of upset force, and two fatal accidents occurred to maintenance personnel as a result of accidental capacitor discharge. Boeing gave a research grant to the University of Washington to study the problems with this technology. One of its graduate students, who was not personally bound to a confidentiality and non-competition agreement, took the technology and made some minor but important improvements and then applied for and was granted a patent, much to the chagrin of Boeing. He started a company in Seattle based on this technology, along with the pursuit of riveting panels which are in a vertical rather than traditionally horizontal plane. He has since also added fixturing to the machine tool architecture. His innovations have plowed a path in the pursuit of electric automatic fastening of aircraft structure, as well as integrated fixturing into the machine tool architecture.

Gemcor needed a proactive response to this electric automatic fastening competitive threat. The first attempt had been to take the same idea of electromagnetic repulsion force generation, but by a different means. The initial experimentation dealt with a solenoid process of generating force. Although this was a simple and proven linear actuator, it did not have the repeatability desired. Next, a dual coil electromagnetic repulsion process was studied. This approach was much more energy efficient and could be designed in a smaller package than the competition. Both these processes were patented by our company. The cost of developing this dual coil electromagnetic process not only was going to be very expensive but also carried an unreasonable uncertainty that the new process might not meet performance expectations. Other linear actuator processes, particularly piezoelectrics, were examined. In the case of the latter, however, the linear distance of expansion and force generation capabilities were not sufficient for upsetting slug fasteners in the range of up to 50,000 pounds-force.

One of Gemcor's customers, an expert machine tool engineer at Deutsche Aerospace in Augsburg, Germany, became disenchanted by the new management style there and decided to leave his company to do freelance machine tool engineering for companies, primarily for ABB. He is highly respected for his machine tool knowledge and particularly his knowledge and appreciation of Gemcor's automatic fastening machinery, with which he had been instrumental in purchasing and implementing. The Airbus

[62] Each sales order being viewed as an independent project.

fuselage assembly factory in Augsburg is still arguably the most efficient automatic panel assembly facility in the world. Within a month of learning about his availability, the author invited him to Gemcor to help in conceiving and designing standardization into current project/products, as well as working with a team to study electric automatic fastening. This small group of five engineers served as a remarkable learning forum because of the combination of their systems and controls background and their extensive experience in the field of automatic fastening of aerostructures. The team reviewed past thinking, competitive technological trends and their portending futures, and customer desires, particularly for product reliability and ease of maintenance. After a long, exhaustive first day of approximately 12 hours, two of the team's engineers came in the next day with a sketch of an all electric system which was different from the electromagnetic technology based concept. Anticipating an electromagnetic actuator, it was pointed out that this concept instead had a ball screw linear actuator controlled by a servomotor. The group discussed the problem with localized continuous force application and the point loading of the balls on the grooved tracks during the very high force upset. At this point the German associate asked if anyone had ever heard of a planetary roller screw. One of the mechanical engineers who had been attending portions of the learning forum interrupted and returned with brochures on planetary roller screws. He said he had been wondering if such a design would be applicable to automatic fastening. The German associate noted that the roller screw design has been used in Europe for over 40 years and its patent had expired long ago. He explained how this design is particularly appropriate for high force applications even in localized distance zones. The team sat stunned, collectively realizing that they had just witnessed the birth of a new paradigm of core technology for a potentially groundbreaking all-electric, automatic fastening system that was better than anything on the market.

The team then spent two days studying attributes of the roller screw design to learn if there was anything possibly wrong with this application. It was much simpler than any other product in the automatic fastening niche, very proven technology but which had never been applied to automatic fastening. The roller screw design would drastically reduce the number of parts used in the machinery, eliminating hydraulics in particular and therefore tremendously reducing the complications in maintenance of these sophisticated systems. Time to market could be significantly improved. This was a Eureka moment, a perfect teaming blend of ideas merging together in a new paradigm all at once. As timing is everything, Gemcor was at a competitive disadvantage technologically in a near-term order placement by British Aerospace Chester for a new automatic fastening system for Airbus wings. The company believed this new electric servo controlled roller screw technology (Escrst™) would be exactly what British Aerospace/Airbus would want to use as a competitive wing production and quality advantage over Boeing. Gemcor therefore rushed to Chester to show them the new ideas graphically along with all of the design's positive attributes. However, by this time British Aerospace had spent two years analyzing the electromagnetic alternative being used by Boeing and had too much financially and ideologically invested to quickly change to the new idea. Gemcor did subsequently prove by throughput analyses to customers that this electromagnetic integrated fixture-machine tool fastening system creates a bottleneck in the wing production line. Furthermore, the entire design is so complex with its large number of parts that its uptime is not very good. The electromagnetic process also has difficulty in changing from slug riveting (single piece solid rivets) to two piece fastener installation because of the difficulty in mass balancing the forces to achieve properly installed fasteners consistently.

From this experience at Chester, Gemcor determined that the era of selling innovative ideas by having the customer look at a drawing was over and that the company needed to actually demonstrate this new technological paradigm because of its radical departure from past methods of automatic fastening. Gemcor also needed to prove that this linear actuator process was equivalent to the hydraulic squeezing process traditionally being used. A test rig was setup to demonstrate as well as collect data for comparative process study, the riveting capability using an 80,000 pound roller screw[63]. This large force

[63] See Exhibit 7-4.

was needed in order to be able to run coupon samples for Boeing and Airbus for their respective 787 and 3XX 600 seat capacity large commercial aircraft. The test apparatus met all expectations and was enthusiastically received by the niche marketplace.

A small automatic riveting system was subsequently built to demonstrate this process, but it was learned that the small machine (10,000 pounds)[64] did not target the market correctly. At this point it was realized that more sophisticated tools were needed to judge the market needs in a less hit and miss, error prone manner. Likewise, tools were needed for downstream manufacturability design aspects. As a result, concurrent engineering, QFD (House of Quality, Voice of the Customer[65]), FMEA, DFMA[66], and solid modeling and simulation (CAD/CAE/CAM) technology for individual and group design were studied and incorporated. The internal culture, however, strongly resisted the new technological paradigm and wanted to move forward instead with new servo hydraulic systems. Even in the face of demonstrable tests and data proving comparable process superiority over hydraulics and magnetic processes, the internal culture balked at a change. The author brought in experienced designers in controls and mechanical design who had no previous automatic fastening background to develop this new product line. Using the house of quality[67], customer requirements were analyzed and translated into technical requirements along with technical conflict reduction and design trades. Extracting or translating the technical requirements from the house of quality customer requests was a difficult process to, in turn, define a product line approach because of the many overlapping requirements which were multidimensional and could not be clearly depicted in the house of quality two-dimensional matrix format. The use of DFMA profoundly influenced Gemcor's design approach on the product line. Also, the book Thinking Beyond Lean by Cusumano[68] had a significant influence on the development of a product line with platform and modularity system architecture. Furthermore, a new product market matrix of organizational and associated information or workflow processes was developed to support the new product development strategies of the corporation.[69]

Given the cultural resistance to the paradigm change of design, the use of a group of competent designers with no previous automatic fastening experience but instead possessing very good machine tool backgrounds turned out to be quite advantageous. This group of independent thinkers had the personality characteristics of not being influenced by others who were trying to dissuade the efforts of the new product development team. Other attributes of machine tools which could be applicable (benchmarking) were extensively examined. One such practice was to use turrets, rotational tool holding plates to allow quick change tooling in a very precise repeatable manner. The team decided to adapt this proven design concept to the new electric automatic fastening system. Again, there was strong internal resistance to the rotary vs. historically linear head transfer process. This type of clean sheet design, at least in this case, shows how important upper management persistence and leadership becomes to effectuate dramatic change for the good of the corporation and its customers.

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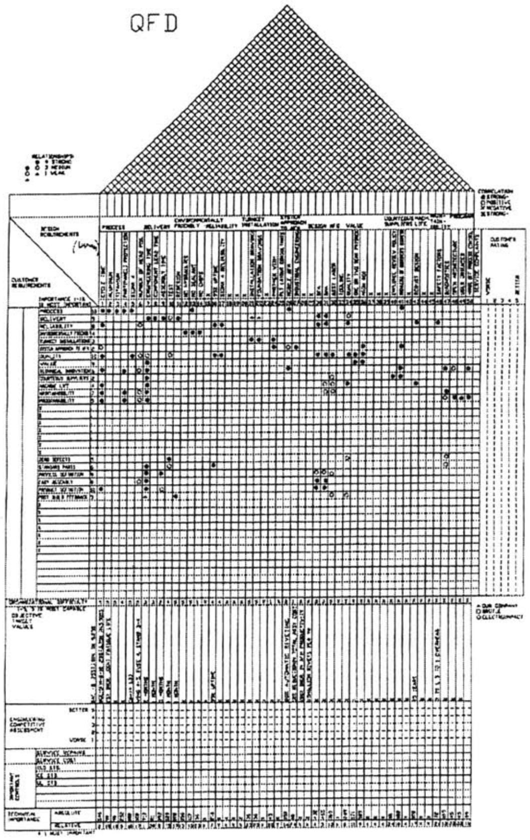
[64] Ibid.
[65] See Exhibit 7-3.
[66] Product Design for Manufacture and Assembly, G. Boothroyd, W. A. Knight Peter Dewhurst, Marcel Dekker publisher, 1994.
[67] See Exhibit 7-3.
[68] Thinking Beyond Lean, How Multi-Project Management is Transforming Product Development at Toyota and Other Companies, M. Cusumano and K. Nobeoka, Free Press, 1998. And, The Power of Product Platforms, M. Meyer and A. Lehnerd, Free Press, 1997.
[69] See Exhibit 8-5, the New Organization Structure of Design and Management Process.

Exhibit 7-3 Quality Function Deployment Escrst™



The resulting rotary head Escrst™ design[70] reduced the number of parts compared to the linear head paradigm by over 90 percent and hence became a platform for the entire new product family[71]. Simulation along with digital solid modeling using Catia and SolidWorks[72] modeling software was used to demonstrate to internal and external customers, including the Board of Directors, that the design concept made sense. Estimates of cost reduction and manufacturability were also calculated. With upper management and Board backing, it was decided to take the plunge and build test articles. Within four months a fully demonstrable unit was operating[73] and was taken to an automatic fastening machine tool show for "mass" customer feedback. It was very enthusiastically received. Gemcor videotaped the unit and included a description of all of the best practices used in the design, calling the tape "Evolution of Design" to further sell internal and external customers. The test unit was then used for DOE testing to assure robustness. These rotary heads have now been installed on two machines for a launch customer. The first machine was accepted by the customer with all tested performance requirements in compliance with the product specifications, and has been used in production for twelve (12) months. The second system has been in production eleven (11) months. Both systems exhibit 98% uptime per Bombardier's calculations. Gemcor is highly dependent on this customer's very positive word-of-mouth for sales in this closely knit fraternity industry. It is expected that the product line will follow an S-curve of sales growth. Bombardier has purchased a third system, and two more are soon to be ordered.

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[70] See Exhibit 7-3.

[71] See Exhibit 7-3.

[72] SolidWorks and Catia are Dassault Systemes products.

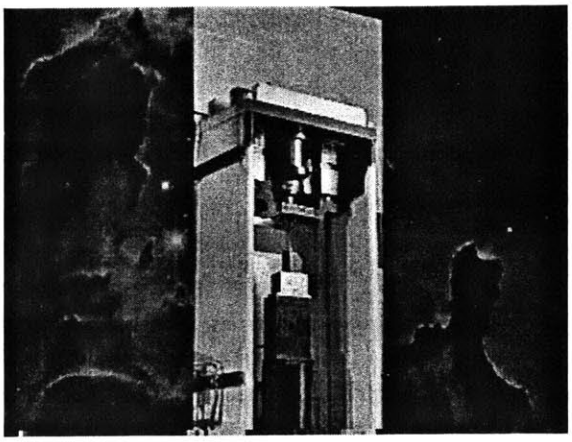
[73] See Exhibit 7-3.

The author presented the Escrst™ system to a select team of 15-20 manufacturing and assembly engineers at Boeing Everett. They have decided to replace and retrofit the Escrst™ technology into all the Everett wing AFS's. Funding is currently being appropriated to purchase a new wing AFS for the 777 wing line and have it certified for production on a noninterference basis. After certification, the changing of all the Everett wing AFS's will commence and continue over several years to spread out the expense and mitigate production impact. For the A3XX the Escrst™ system coupled with highly innovative flexible fixturing is being considered by BA Airbus. A similar replacement or retrofit of the Gemcor AFS's with the Escrst™ is also planned by BA Airbus.

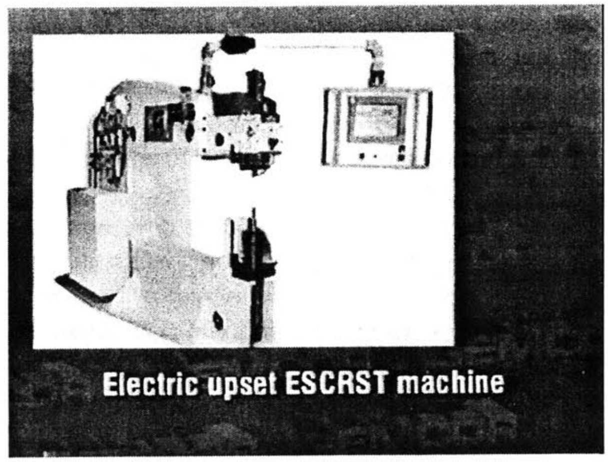
As stated earlier, the company's plan was to design a product family with the rotary head as the platform of design and Escrst™ as the core technology. From the house of quality matrix, the team along with upper management, the sales department, marketing, and selected customers as a group reached a consensus on the different products in the product line and their anticipated derivatives. Individual intent specifications, product tree decompositions, and subcategorized costs by product line within the product family, along with solid models depicting their form, were produced. Critical components and key characteristics were determined and made part of the specifications. Although the concepts had basic boundaries of form, there was still an iterative or heuristic design effort to keep the designs within cost constraints. Concurrent with the effort to reduce parts and complexity as compared to historical designs, pricing of the standard products within the family was targeted to be significantly better than the competition's. The design and build costs by which the concepts had to be constrained were determined by cost ratio modeling. In effect, this final process took a target market priced, top-down design, cost driven, concept development approach, requiring many iterative concept studies to get the function and form in line with the cost constraints.

Downstream influences significantly affected the design and concepts developed. The platform and modularity of the designs allow for better MRP and JIT scheduling because of the market forecastability and the predictability of standard submodule and subcomponent needs and timing in order to minimize

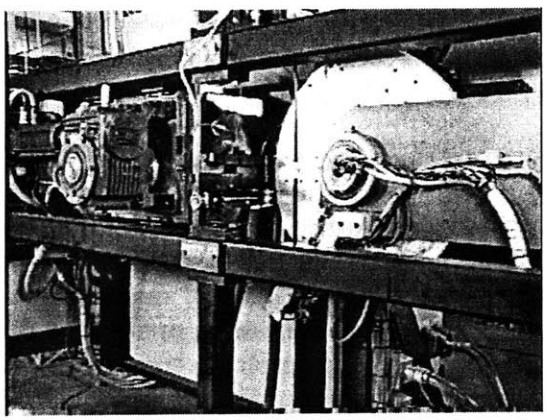
Exhibit 7-4
Escrst™ Robustness Testing and Product Development



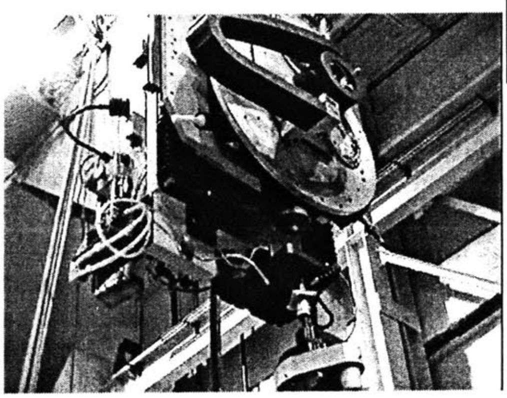
80,000 lbs-F Test Rig



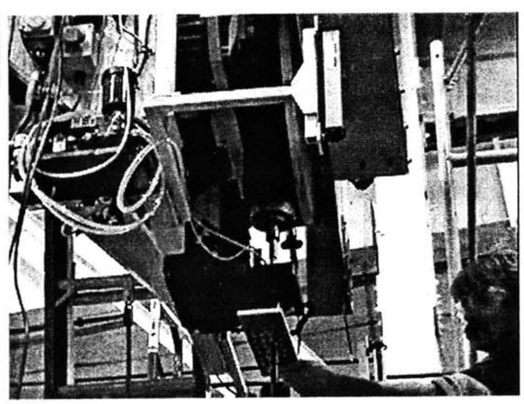
10,000 lbs-F Full System



Escrst™ Rotary Heads DOE Test Rig



1st Escrst™ Product



1st Escrst™ Product

inventory holding costs and final product time to market. Also, operator training and service timing requirements were taken into account. The machines have remote accessibility as a standard feature to allow the engineers to look directly into the operating code to assist in any service requirements from a distance, affording rapid response time for the customer. This product line has been designed with a 99 percent system reliability intent and a guarantee to customers 95 percent uptime. In many respects an automatic fastening machine is analogous to a Xerox copier (or digital document system). The customer is highly dependent on the automation and just wants the machinery to function reliably. Using FMEA, much effort was expended upfront to assure that design risks were mitigated and robustness designed in.

The entire project of this product development has been controlled in part by MSProject linked with Gemcor's enterprise information system and new organization structure. Lotus Notes serves as the workflow network system which allows easy database file exchange from different LAN and operating system environments (NT and Unix). Gemcor applied for and has been granted a patent for the Escrst™ design, the core technology, and has a patent pending on the rotary head design. The new system is 25 percent faster than the next best alternative system on the market and 50 percent faster than older automatic fastening machinery. All interface points of the modules have been standardized for ease of coupling in different configuration forms.

The software and controls are of considerable interest in this integrated hardware/software system. The software is a layered architecture type. The top layer is the human machine interface graphic software for operation, maintenance and process control of the system, followed by a CNC motion control layer, which is in turn followed by the PLC control for operating several subroutines and is itself a module. The final layer is a set of very high-speed, precise, specialized, software/processor axes controllers. In this particular case the HMI screens are bilingual.

The actual form of the automatic fastening system is basically determined by the geometry of the aircraft panels, which determines the machine's size, and by the fastener selection for the panels, which determines the force to which the machine must apply and react. Its concept is a c-frame which can reach over horizontally held panels. The c-frame has an upper and lower head attached rigidly to the c-frame to maintain alignment. The c-frame is able to react against the applied forces of the heads within a tolerable deflection to prevent wiping of the fasteners. The wing or fuselage panels are pretacked with a few fasteners in a rigid fixture to determine their geometry accurately for subsequent final assembly. The fixtures have inner frames which detach and by crane are hoisted, moved to the automatic fastening system (AFS) system, and positioned accurately onto tooling pins until the inner frame is seated. The airframe is clamped into position automatically with hold down clamps. The frame holds the panel and positions the part in 'Z', 'a' and 'b' axes. The c-frame is positioned in 'X' and 'Y' directions under CNC control. The single operator sits at the workstation console with a Human Machine Interface (HMI) Windows NT software system. The HMI interfaces with a CNC and a high speed, high precision, motion control software/hardware subsystem for high-speed, very accurate axes motion of large, heavy masses. The operator initiates the start sequence after the panel is located in position, and the panel is automatically fastened, assembled hands off. The HMI subsystem controls the entire multi-fastening process, including machine and part positioning, and records statistical process control (SPC) data for the Federal Aviation Administration (FAA) and the Joint Aviation Authorities (JAA) quality required records for quality aspects of the hole and fastener for each panel. The fasteners are located in vibratory feeding bowls on a platform of the c-frame by size, length and style. The offline CAD/CAM produced part program determines the size, length and style of fastener and position for each installation location. All axes can operate simultaneously for maximum speed. The fastener selected is pneumatically fed from a bowl through tubes to the upper head where at the proper time in the cycle it is injected into fingers which hold the fastener for placement into the drilled hole. After the fastener is installed successfully, the machine system moves to the next fastening location.

The Escrst™ technology model is depicted in Figure 7.2. An inter-related set of spreadsheets (not shown) are used to select the optimal choice of components for the Escrst™ subsystem with respect to the required force, longevity, acceleration, deceleration, and velocity characteristics.

The new product strategy has a simple guiding principle: to render obsolete and replace Gemcor's current products with better ones through continuous product platform renewal. While this may threaten some employees, customers generally prefer dealing with strong innovators who will be introducing better products tomorrow. As a corollary idea, management must achieve leverage in its product platforms through standardization, modularity, and the economic benefits of higher-volume procurement of common subsystem components.

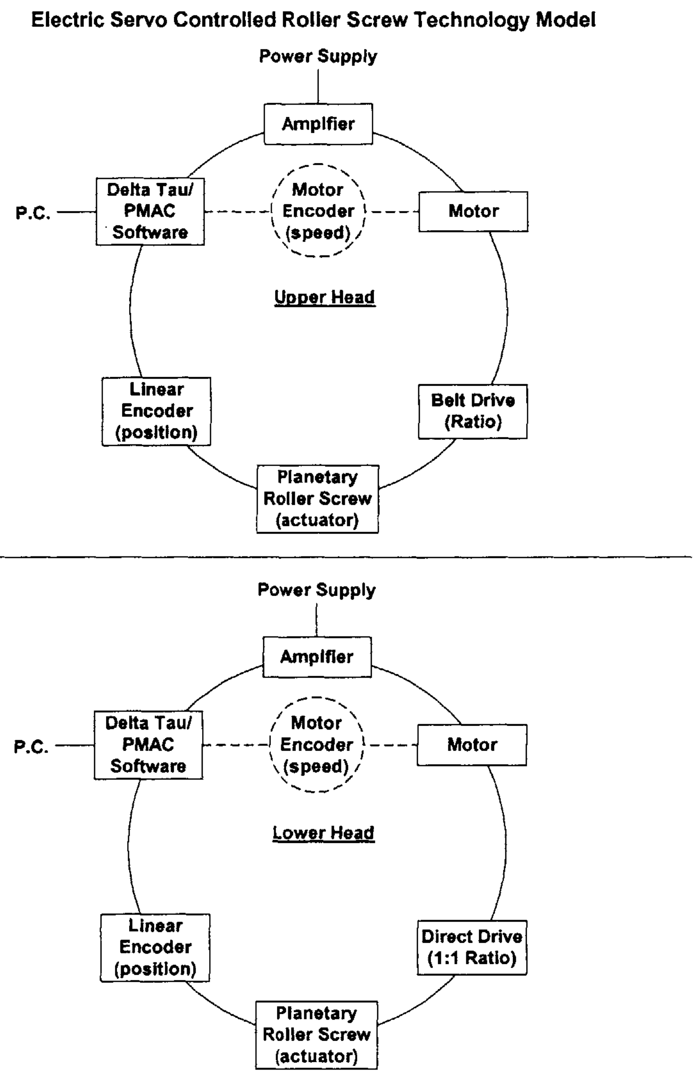


Figure 7.2 Escrst™ Model

Design Structure Matrix (DSM) Usage for Automatic Fastening System: Theoretical Functional Grouping and Design

The primary functions and attributes of an automatic fastening system were listed and put in a DSM to discern the input-output relations and their coupling strengths for the purpose of understanding and application to AFS designs. The DSM's and the derived groupings shown in Exhibit 7-6 highlight the importance of the input (panel geometries, fasteners, electric power, panel assembly part program CAD/CAM generated from Solid Model Simulator) to the automatic fastening system (AFS). The coupling measures among the functions were S = Communication Signals, EP = Electric Power, and MI = Mechanical Interface. The mechanical interface seems to be the most important in determining the architectural form since the communication and power can be distributed by cable easily, giving flexibility in its form and chunk proximity. Based on their "attractiveness strength" couplings, the chunks of "input," "Sensors for Motion Control," and "Positioner" should have their teams and designers grouped together. Intuitively this grouping makes sense because the DSM in a manner advocates designing the panels for automation manufacturability at the same time as dynamic and structural design occurs. Likewise, the DSM suggests the AFS supplier and the customer group together to design the panels and assembly automation systems. Undoubtedly this kind of joint design will improve cost, time, structural fatigue life and strength. However, today there is still too much of a barrier of communication between customer and supplier and lack of combined thinking and effort. The initial matrix and its partitioned partner are shown in Exhibit 7-5. It is clear that the functions are very interactive. However, the functions can be summarized better by functional specialty as was done and displayed in Exhibit 7-6. Taking this functionally specialized grouping, another DSM was made, Exhibit 7-7, which after partitioning and tearing as described in the exhibit results in a nice optimization showing a clear design separation desired except for the expected coupling and integration possibility of sensors for motion control, AFS end effectors, c-frame, and positioner. A functional decomposition showing the preferred groupings is displayed in Figure 7.3. The object process model, Figure 7.4, is another means of depicting the functional interaction within the AFS highlighting the process and objects comprising the AFS for specification and design development.

Functions, Inputs and Outputs

Panels' Geometries
Panel Production Schedule
Fasteners: 2-Piece (various types and lengths)
Fasteners: Rivets (various types and lengths)
Electric Power
Pneumatic Power
Panel Assembly Part Program CAD/CAM generated from Solid Model Simulator
Drive Motion: Electric Drives
Drive Motion: Linear Actuators
Drive Motion: Gear Boxes
Sensors for Motion Control
Fastener Tooling
Automatic Fastening End Effectors (heads) C-Frame
Positioner: X-Axis
Positioner: Y-Axis
Positioner: Z-Axis
Positioner: a-Axis
Positioner: c-Axis
Controls: Software

Controls: HMI
Controls: Process Control & Statistical Process Control
Controls: I/O
Cabinet: Interbus System
Cabinet: Computer Hardware
Work Force: Operators
Work Force: Maintenance
Work Force: Manufacturing Engineers
ARS: Automatic Fastener Select and Feed System
Multiple Panel Style Holding Frame Clamps
Power Distribution: Power Transformers
Power Distribution: Breakers
Power Distribution: Distribution
Completed Sub-Assembly Airframe Panel Structures

Exhibit 7-5
Design Structure Matrix
of an Automatic Fastening System

This exhibit demonstrates the highly interactive functionality of automatic fastening systems. The primary functions are contained in the design structure matrix below. Other details are subcontained in these primary functions.

		Panels' Geometries	Panel Production Schedule	Fasteners: 2-Piece (various types and length	Fasteners: Rivets (various types and lengths	Electric Power	Pneumatic Power	Panel Assembly Part Program CAD/CAM gene	Drive Motion: Electric Drives	Drive Motion: Linear Actuators	Drive Motion: Gear Boxes	Sensors for Motion Control	Fastener Tooling	Automatic Fastening End Effectors (heads) C-	Positioner: X-Axis	Positioner: Y-Axis	Positioner: Z-Axis	Positioner: a-Axis	Positioner: c-Axis	Controls: Software	Controls: HMI	Controls: Process Control & Statisical Process	Controls: I/O	Cabinet: Interbus System	Cabinet: Computer Hardware	Work Force: Operators	Work Force: Maintenance	Work Force: Manufacturing Engineers	ARS: Automatic Fastener Select and Feed Sys	Multiple Panel Style Holding Frame Clamps	Power Distribution: Power Transformers	Power Distribution: Breakers	Power Distribution: Distribution
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Panels' Geometries	1							1																									
Panel Production Schedule	2					1	1																										
Fasteners: 2-Piece (various types and lengths)	3							1																									
Fasteners: Rivets (various types and lengths)	4							1																									
Electric Power	5																						1	1	1								
Pneumatic Power	6																																
Panel Assembly Part Program CAD/CAM generated from Solid Model Simulator	7	1		1	1																							1					
Drive Motion: Electric Drives	8	1	1			1															1	1	1	1	1	1						1		1
Drive Motion: Linear Actuators	9	1	1			1															1	1	1	1	1	1								
Drive Motion: Gear Boxes	10	1	1																														
Sensors for Motion Control	11	1				1		1	1		1										1	1	1	1	1	1								
Fastener Tooling	12	1		1	1			1																									1
Automatic Fastening End Effectors (heads) C-Frame	13	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1	1	1				1				1
Positioner: X-Axis	14	1	1						1		1			1																			
Positioner: Y-Axis	15	1	1						1		1			1																			
Positioner: Z-Axis	16	1	1						1		1			1																			
Positioner: a-Axis	17	1	1						1		1			1																1			
Positioner: c-Axis	18	1	1						1		1			1																			
Controls: Software	19			1	1			1	1	1	1	1		1								1	1	1	1	1					1	1	1	1
Controls: HMI	20			1	1			1	1	1		1		1							1		1	1	1	1	1	1	1	1	1	1	1	1
Controls: Process Control & Statisical Process Control	21			1	1			1	1	1		1		1							1	1		1	1	1			1	1	1	1	1	1
Controls: I/O	22		1			1			1	1		1		1							1	1	1		1	1				1	1	1	1	1
Cabinet: Interbus System	23					1			1	1		1		1							1	1	1	1		1				1	1	1	1	1
Cabinet: Computer Hardware	24					1		1													1	1	1	1	1		1	1	1	1	1	1	1	1
Work Force: Operators	25		1	1	1			1														1	1			1			1					
Work Force: Maintenance	26		1	1	1	1	1	1														1	1			1			1					
Work Force: Manufacturing Engineers	27		1	1	1	1	1	1													1	1	1			1								
ARS: Automatic Fastener Select and Feed System	28		1	1	1	1	1	1	1												1	1		1	1	1								1
Multiple Panel Style Holding Frame Clamps	29	1	1			1			1												1	1		1										1
Power Distribution: Power Transformers	30					1															1	1		1									1	
Power Distribution: Breakers	31					1															1	1		1										
Power Distribution: Distribution	32					1															1	1			1	1					1		1	
Completed Sub-Assembly Airframe Panel Structures	33	1	1																														

Partitioned:

Pneumatic Power	6	6																																
Panels' Geometries	1		1					1																										
Panel Production Schedule	2	1		2			1																											
Fasteners: 2-Piece (various types and lengths)	3				3			1																										
Fasteners: Rivets (various types and lengths)	4					4		1																										
Electric Power	5						5																1	1	1									
Panel Assembly Part Program CAD/CAM generated from Solid	7		1					7																				1						
Drive Motion: Electric Drives	8		1	1					8												1	1	1	1	1	1						1		1	
Drive Motion: Linear Actuators	9		1	1			1			9											1	1	1	1	1	1									
Drive Motion: Gear Boxes	10		1	1							10																							
Sensors for Motion Control	11		1				1	1	1		1	11									1	1	1	1	1	1									
Fastener Tooling	12		1		1	1		1					12																					1	
Automatic Fastening End Effectors (heads) C-Frame	13	1	1	1	1	1	1	1		1	1	1	1	13	1	1	1	1	1	1	1	1	1	1	1				1				1	
Positioner: X-Axis	14		1	1					1		1			1	14																			
Positioner: Y-Axis	15		1	1					1		1			1		15																		
Positioner: Z-Axis	16		1	1					1		1			1			16																	
Positioner: a-Axis	17		1	1					1		1			1				17												1				
Positioner: c-Axis	18		1	1					1		1			1					18															
Controls: Software	19				1	1		1	1	1	1	1		1						19	1	1	1	1	1					1	1	1	1	
Controls: HMI	20				1	1		1	1	1		1		1						1	20	1	1	1	1	1	1	1	1	1	1	1	1	
Controls: Process Control & Statisical Process Control	21				1	1		1	1	1		1		1						1	1	21	1	1	1			1	1	1	1	1	1	
Controls: I/O	22			1			1		1	1		1		1						1	1	1	22	1	1				1	1	1	1	1	
Cabinet: Interbus System	23						1		1	1		1		1						1	1	1	1	23	1				1	1	1	1	1	
Cabinet: Computer Hardware	24						1	1												1	1	1	1	1	24	1	1	1	1	1	1	1	1	
Work Force: Operators	25			1	1	1		1													1	1			1	25		1						
Work Force: Maintenance	26	1		1	1	1	1	1													1	1			1		26	1						
Work Force: Manufacturing Engineers	27	1		1	1	1	1	1												1	1	1			1			27						
ARS: Automatic Fastener Select and Feed System	28	1		1	1	1	1	1	1											1	1		1	1	1				28					1	
Multiple Panel Style Holding Frame Clamps	29		1	1			1		1											1	1		1							29				1	
Power Distribution: Power Transformers	30						1													1	1		1								30	1		
Power Distribution: Breakers	31						1													1	1		1									31		
Power Distribution: Distribution	32						1													1	1			1	1					1		1	32	
Completed Sub-Assembly Airframe Panel Structures	33		1	1																														33

Exhibit 7-6
The Functional Matrix has Highly Coupled Functions, Some of which can be Grouped for Modularity

Input to System:
Panels Geometries (by schedule)
Fasteners
2-Piece
Rivets (various types and lengths)
Electric Power
Pneumatic Power
Panel Assembly Part Program CAD/CAM generated from Solid Model
Simulator

Drive Motion
Electric Drives
Linear Actuators
Gear Boxes

Sensors for Motion Control

Fastener Tooling

Automatic Fastening End Effectors (heads)
C-Frame

Positioner

Controls
Software
HMI
Process Control
I/O
Cabinet
Interbus System
Computer Hardware

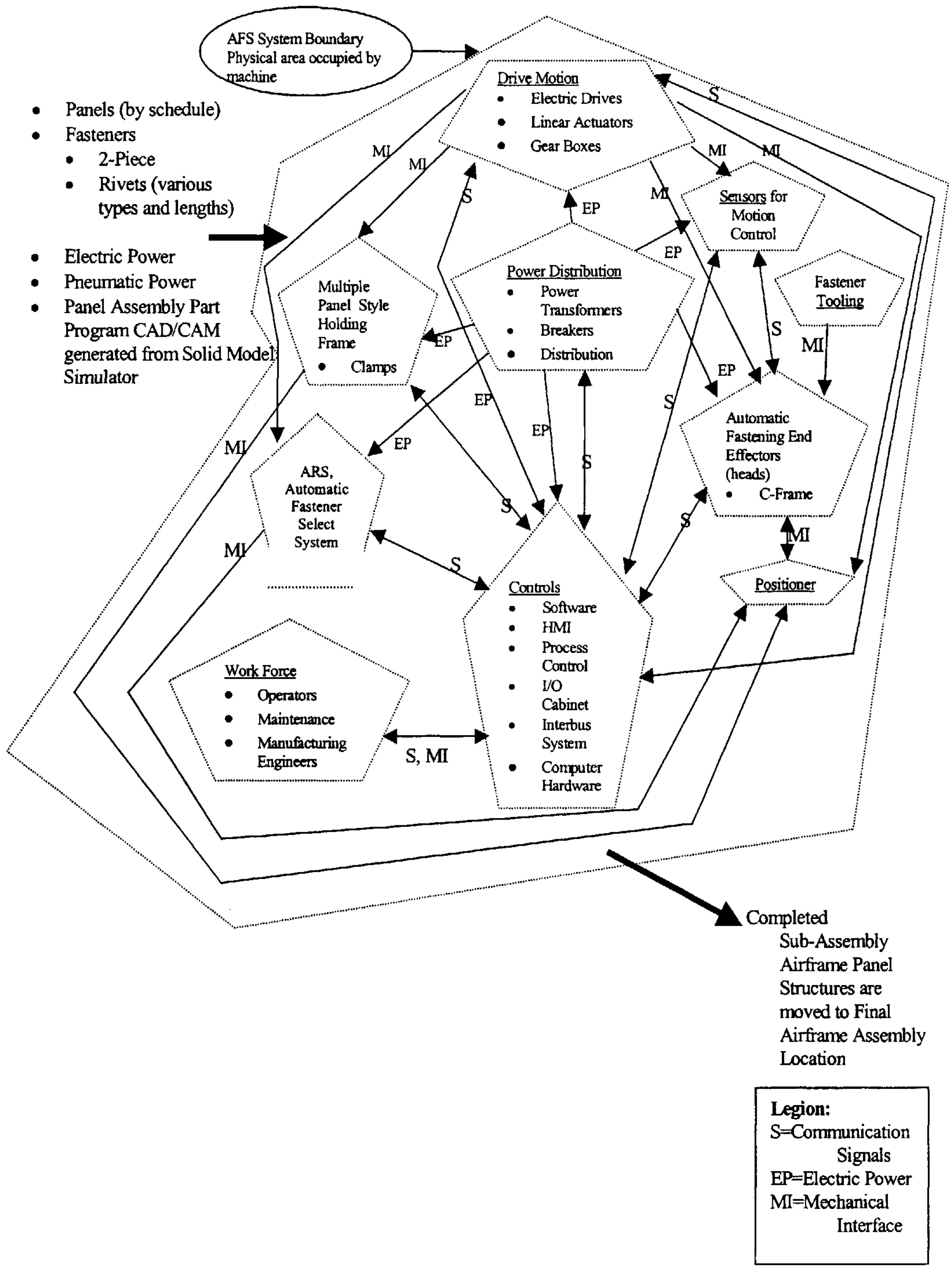
Work Force
Operators
Maintenance
Manufacturing Engineers

ARS
Automatic Fastener Select and Feed System

Multiple Panel Style Holding Frame
Clamps

Power Distribution
Power Transformers
Breakers
Distribution

System Output:
Completed Sub-Assembly Airframe Panel Structures are moved to Final Airframe Assembly Location



Reducing the partitioned functions in Exhibit 7-5 to the groupings identified in Exhibit 7-6 and partitioning analysis of the interdependencies of these groups in Exhibit 7-7 results in high interaction of controls, sensors and positioner functions. Also, controls is highly associated with the workforce, ARS, fixture clamps and power distribution. Of course all functions result in the complete panel subassemblies.

Exhibit 7-7
The Resulting Design Structure Matrix

Name		1	2	3	4	5	6	7	8	9	10	11	12
Panels' Geometries et al	1												
Drive Motion	2							1				1	
Sensors for Motion Control	3		1			1		1				1	
Fastener Tooling	4												
AFS End Effectors, C-frame	5		1	1	1		1	1				1	
Positioner	6		1			1				1	1		
Controls	7		1			1	1		1	1	1	1	
Workforce	8							1					
ARS	9		1					1				1	
Fixture Clamps	10		1					1				1	
Power Distribution	11							1					
Completed Panel Subassemblies	12	1	1	1	1	1	1	1	1	1	1	1	

After partitioning:

		1	4	2	3	5	6	7	8	9	10	11	12
Panels' Geometries et al	1												
Fastener Tooling	4												
Drive Motion	2							1				1	
Sensors for Motion Control	3			1		1		1				1	
AFS End Effectors, C-frame	5		1	1	1		1	1				1	
Positioner	6			1		1				1	1		
Controls	7			1		1	1		1	1	1	1	
Workforce	8							1					
ARS	9			1				1				1	
Fixture Clamps	10			1				1				1	
Power Distribution	11							1					
Completed Panel Subassemblies	12	1	1	1	1	1	1	1	1	1	1	1	

Controls have a highly interactive effect on the entire system which is not surprising. Within the partition additional groups are clustered. Tearing Controls and Completed Panel Subassemblies and subsequent repartitioning show the following grouping of Sensors for Motion Control, AFS end effectors, C-frame and the Positioner.

		1	4	7	2	10	8	9	3	5	6
Panels' Geometries et al	1										
Fastener Tooling	4										
Workforce	7										
Drive Motion	2			1							
Power Distribution	10			1							
ARS	8			1	1						
Fixture Clamps	9			1	1						
Sensors for Motion Control	3			1	1					1	
AFS End Effectors, C-frame	5		1	1	1				1		1
Positioner	6				1	1		1		1	

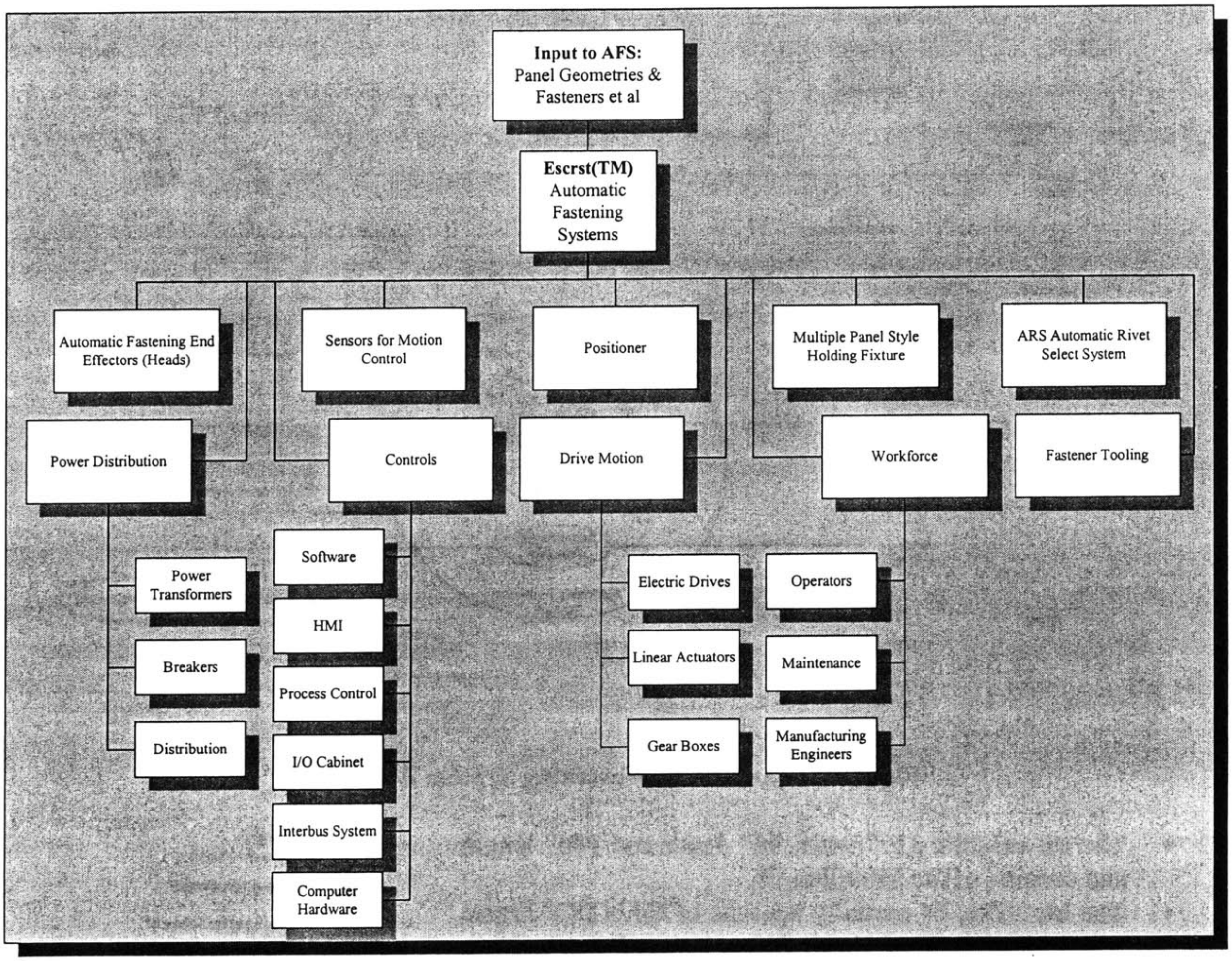


Figure 7.3 Escrst™ Functional Decomposition Derived from Exhibit 7-6 and 7-7

The decomposition in Figure 7.3 is not surprising from the natural groupings based on functional independence. The design, however, may take a variety of forms as can be seen in Exhibits 7-8 through 7-14. The functional DSM's do not clearly show the design form best suited for an AFS, but the process of developing the DSM's did stimulate ideas on how to further combine functionality within a certain group and possibly how to reduce dependence on groups, such as workforce. It is hard to put in the DSM a technological change occurring which is affecting a group's internal functioning. One technological change being incorporated is the elimination of the CNC by software emulation. The actual motion control function is not eliminated because it is fundamental to the AFS operation, but the complex software layering and associated hardware architecture for the module is eliminated and replaced by a single operating environment. The advantages are lower software and hardware cost and easier debugging. Additionally, the cycle is faster, less space is required, and fewer possibilities of error are a result. The design form may or may not blend the functionalities, given the normally very high variety of design possibilities. In aircraft, for example, the wings functionally are for lift and fuel carrying capacity, and the fuselage for carrying payload. A so-called flying wing is a blended design combining the functions of lift, fuel, and payload capacity. These blended function possibilities are difficult to discern from the DSM or the functional decomposition, yet the exercise of using the tool stimulates alternative design thinking which may lead to elegant designs.

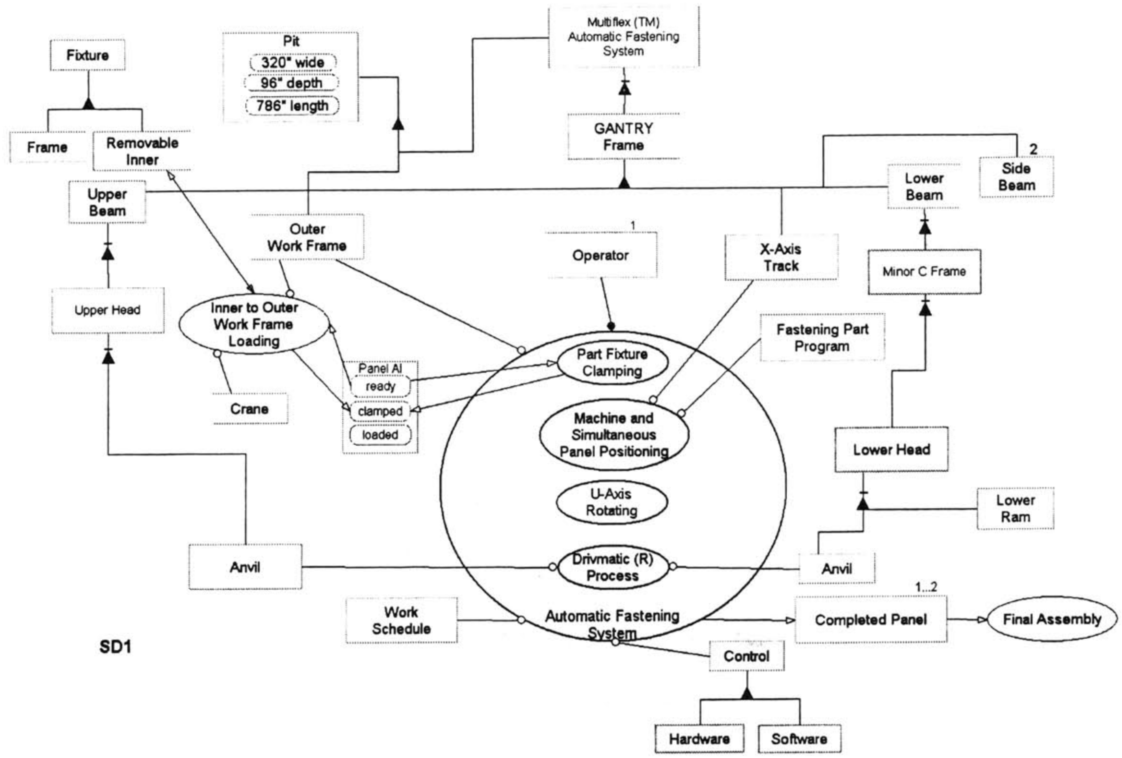
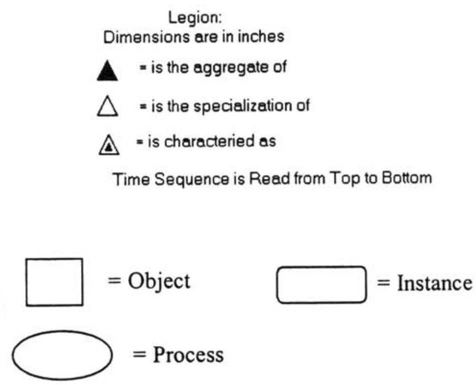


Figure 7.4 Automatic Fastening System Zoom In[74]



- The Pit exhibits 320" wide, 96" depth and 786" length and consists of the Multiflex ™.
- The Multiflex ™ partially consists of GANTRY Frame which consists of the Upper Beam, Lower Beam and two Side Beam.
- The Automatic Fastening System consists of Part Fixture Clamping, Machine and Simultaneous Panel Positioning, U-Axis Rotating and the Drivmatic® Process.
- The Outer Work Frame, Work Schedule, Control and Operator enable the Automatic Fastening System.
- The Automatic Fastening System outputs one or two Completed Panel.
- Completed Panel one to many input to Final Assembling.
- The Fixture consists of the Frame and the Removable Inner.
- The Crane moves the Removable Inner and positions it into the Work Frame Outer.
- Part Clamping receives the Inner Work Frame and indicates a clamped condition followed by a loaded condition.
- The Machine and Simultaneous Panel Positioning is enabled by the X-Axis Track and the Fastening Part Program.
- The Drivmatic® Process is enabled by the Upper Head Anvil and Lower Head Anvil.
- The Control consists of the Hardware and the Software.

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[74] Also, refer to Figures 6.6, 6.7, and 6.8.

Alternative Architectures Considered

Core Technology Architectures

It is difficult in a short space to describe all the different architectural alternatives considered. Instead, the main drivers for comparison will be briefly discussed. To start, the past paradigm of upper head for automatic fastening systems was characterized by being a series of linear translations. The number of positions in the upper head could be as few as two, one for drilling and one for rivet insertion, and up to 6 positions, drill the hole, work harden the hole, ream the hole, apply sealant to the fastener, insert the fastener, and end mill shave the fastener flush with the aerodynamic surface. The linear head could be mounted in line with the c-frame or at 90 degrees to the c-frame. The 90 degree architecture provided a closure clearance to panels, but the side movement forces during position transfers caused vibration in the upper c-frame which delayed the cycle time. The in line architecture did not have this vibration, yet it did not provide the close clearance, and the more positions on the head, the farther it extended out over the panel. Maintenance on the in line head was more difficult too. Furthermore, the rotary head subsystem architecture was more suitable than the linear for modular flexibility in its attachment to various positioner geometries. (See Figure 7.5 for the design comparison and Figure 7.6 for their operation sequence timing charts) The basic weldments which fit around a structure are of a fairly elementary mechanical design and can be quickly customized if a standard design is not "on the shelf" to accommodate a new aerostructural shape.

On the other hand, the rotary head's centrifugal forces create twisting moments on the supporting heavy steel weldment. These moments have not demonstrated any appreciable vibration. Other comparisons are found in the Table 7-1.

Gemcor
Features Comparison

		Escrst™	Hydraulic
1.	Upper Head	Rotary Electric	Linear Hydraulic
2.	Upper Head Pos.	Up to 6	Up to 5
3.	Spindle Type	Electric	Hydraulic
4.	Drill RPM	3,000-18,000	500-12,000
5.	Countersink Cntrl.	Software	Hard Stop
6.	Drill Feed Cntrl.	Roller Screw	Hydraulic
8.	Rivet Upset	Servo Electric	Servo Hydraulic
9.	Upset Modes	Position	Position
10.	Process	Squeeze	Squeeze
11.	Cycle time(clamp-unclamp)	2.10 sec.	2.80 sec.
12.	Qty Spindles	Up to 3	Up to 2
13.	Qty Upper Anvils	Up to 3	1
14.	Manual Tool Change	Not required*	Yes

*** Significantly Improves Throughput**

Table 7-1 Escrst™ Rotary Head vis-à-vis Hydraulic Linear Head Feature Comparison

The comparison of Escrst™ to the 'low voltage' electromagnetic system (LVEMR) is shown in Table 7-2.

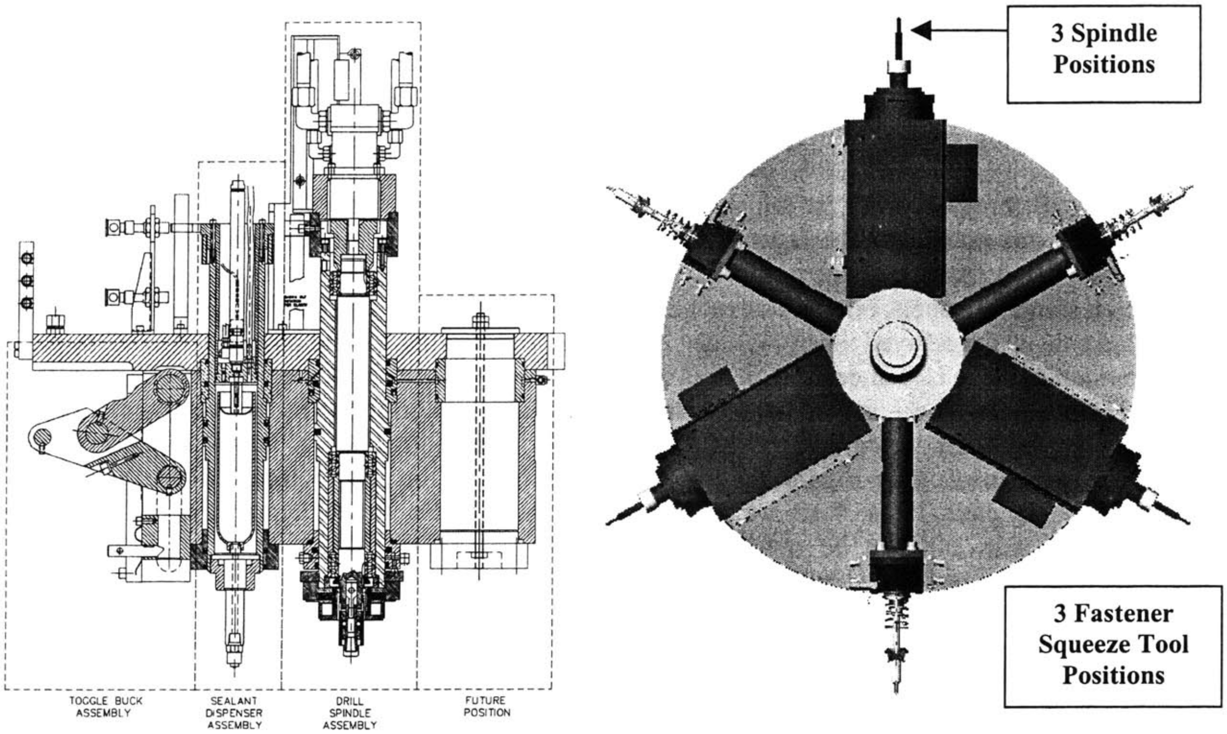


Figure 7.5 Comparison of the Linear Style to the Rotary Design

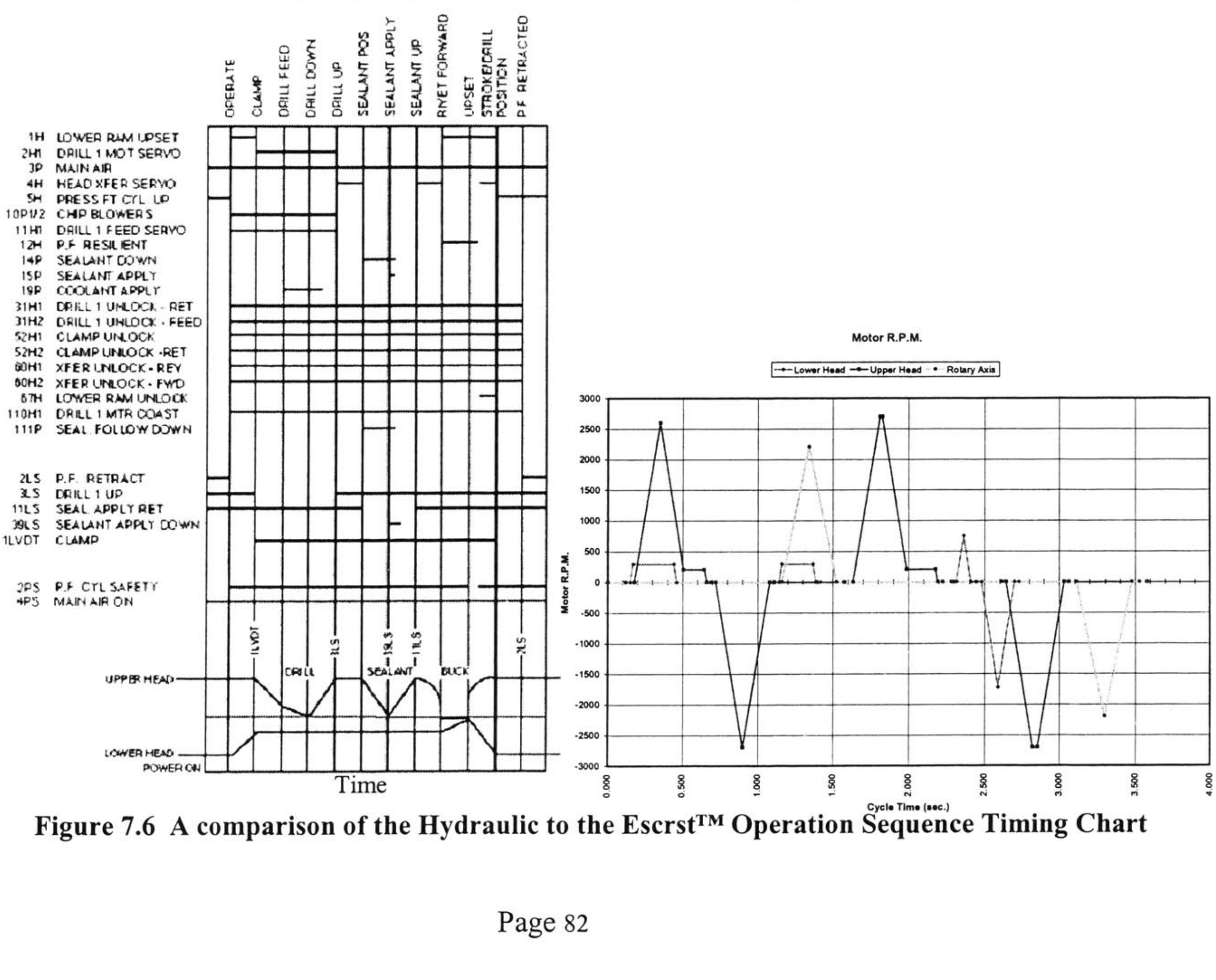


Figure 7.6 A comparison of the Hydraulic to the Escrst™ Operation Sequence Timing Chart

Table 7-2 compares and shows the advantages of the Escrst™ vis-à-vis the LVEMR.

ESCRST™ vs. LVEMR

- ESCRST™
  - Faster cycle
  - Total throughput improved by 30% to 80%
  - Able to easily accommodate a wide range of fasteners
  - Safer than lvemr
    - 100 amps DC
    - very low electromagnetic radiation
  - Total control during fastener forming process
    - Constant process feedback for force, actuator position & motor torque
  - Imparts energy to fastener
  - Single forming process
  - No fastener cracks
- LVEMR
  - Slower process
  - Requires double impacts to prevent gaps and not crack fasteners
  - Increases the probability that cracks occur in hard alloys
  - Range of fasteners is limited, complexity & change over time is significant
  - 15,000 to 20,000 amps DC
  - High electromagnetic radiation
  - No control after release of potential energy
    - No process feedback after release
  - Imparts energy to aircraft part
    - stresses panel

Table 7-2 Escrst™ vs. LVEMR

Other process architectures were compared to Escrst™ with the results listed in Table 7-3:

Characteristics of Escrst™

- Safe relative process
- Long life
  - > 1 billion cycles
- High force
  - 4,000 to 80,000 lbs.
- Variable velocity control during fastener forming using the latest in high speed motion control technology
- Low maintenance
- Can be used for the following fasteners:
  - Rivets
  - Slug rivets
  - Bolts
    - Interference Insertion
    - Collar swaging
- Very fast, 70ms upset up to 50,000 lbs.
- Low noise (dBa)
- High efficiency >90%
- Uses digital technology

Table 7-3 The Comparative Characteristics of Escrst™ to other processes

Alternative linear actuators were considered with the interesting comparisons highlighted in Table.7-4.

Planetary Roller Screws vs. Other Linear Motion Technologies (used in electronic position applications)	Planetary Roller Screws	Hydraulic Cylinders	Acme Screws	Ball Screws	Pneumatic Cylinders
Load ratings	Very high	Very high	High	High	High
Lifetimes	Very long, many times greater than ball screws	Can be long with proper maintenance	Very low due to high friction & wear	Moderate	Can be long with proper maintenance
Speed	Very high	Moderate	Low	Moderate	Very high
Acceleration	Very high	Very high	Low	Moderate	Very high
Electronic positioning	Easy	Challenging	Moderate	Easy	Very difficult
Stiffness	Very high	Very high	Very high	Moderate	Very low
Shock loads	Very high	Very high	Very high	Moderate	High
Friction	Low	High	High	Low	Moderate
Efficiency	>90%	<80%	~40%	>90%	<50%
Installation	Compatible with standard servo electronic controls	Complex; requires servovalves, plumbing, filtering, pumps, & linear positioning sensing	User may have to engineer a motor/ actuator interface	Compatible with standard servo electronic controls	Very complex; requires physical stops, plumbing, filtering, lubrication, compressors, & linear positioning sensing
Maintenance	Very low	Requires specialized personnel	High due to poor wear characteristics	Moderate	Moderate
Environmental concerns	Minimal	Hydraulic fluid frequently leaks; requires cleanup & disposal	Minimal	Minimal	High noise levels

Table 7-4 Planetary Roller Screws vs. Other Linear Motion Technologies

The economic benefits are summarized in Table 7-5.

Customer Return-on-Investment

- Faster throughput
- Quicker cycle time
- Lower maintenance
- High safety
- Reduced operating costs
  - Reduced consumable costs
  - Less energy consumption
- Better fuel tightness
- Improved uptime
  - High reliability
- Stronger joints
- Greater fatigue life
- Coupon reduction
- Reduced rework
  - reduced possibility of panel damage
  - Tipped fastener protection
- Wide range of fasteners with same screw

Table 7-5 Escrst™ Return on Investment vs. Other Processes Studied

Major Architectures

There is always a risk of a departure from the past proven architecture, which includes customer acceptance, technological risk, robustness risk, financial risk, intellectual property rights and others. Internal tensions between the past and the new led to a compromise of offering the new Escrst™ electric modules on current as well as new architectures. This decision also made retrofitting to the existing installed base of AFS's more psychologically appealing. Computer hardware can be a sensitive area for customers who may have standardized their company on certain brand names. Also, the computers and softwares are the most rapid zone of change so it was decided to customize to market demand as required. The basic logic of functionality, however, is not anticipated to change as often, thus preserving robustness. A baseline design using Fanuc and Delta Tau with Cimplicity HMI was chosen, along with a layered software architecture. A better, nonlayered, single operating environment software architecture exists which is lower cost due to its emulation of a CNC, thereby eliminating the CNC hardware. One customer is preparing to buy this object process control (OPC). Interbus is used for I/O signal transmission which multiplexes communications throughout the integrated system with minimal wiring.

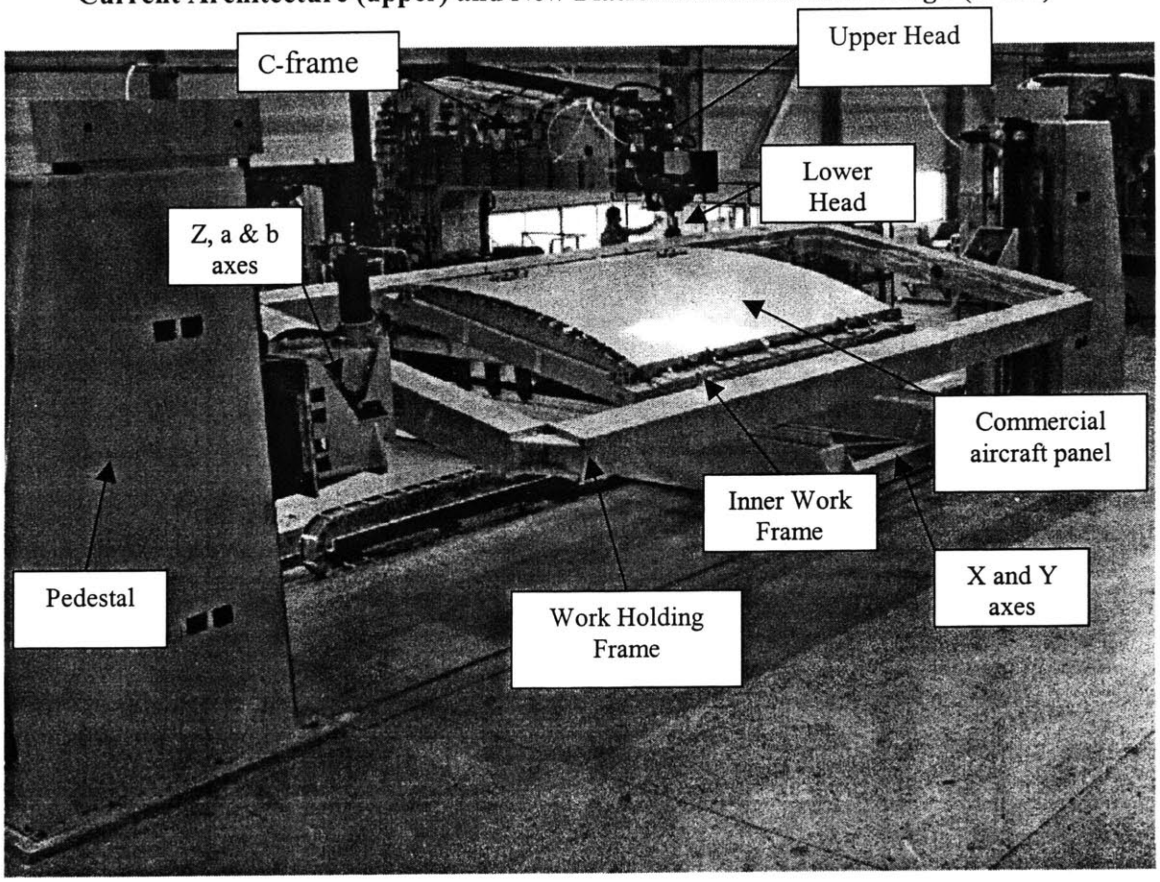
A traditional AFS architecture is shown in Exhibit 7-8 which highlights the main subsystems. It is characterized by a c-frame embedded in an x-y carriage possessing a low center of gravity for faster movement driven by a rack and pinion with electric motor with encoder feedback for servo control. The end pedestals provide a, b and Z axis motion by an electric servo controlled proprietary high accuracy zero backlash gear box and ball screw. The panel parts, an Airbus center wing box in this case, are clamped into a fixture offline, and the inner frame of the fixture is removed and by overhead crane taken to the outer workframe of the AFS where it is accurately positioned by a cone pin and diamond shaped pin and held down by automatic clamps. The operator stationed on the machine brings the machine into its home position, then initiates the part program that automatically locates the seam starting position by moving to a resynchronization point for vision alignment. The system operates under five axis simultaneous control for maximum speed. The part programs are generated offline using Catia/Deneb simulation to avoid the tedium and cost of digitizing. Sensors do exist on the end effectors in the case that panel variations normality and edge margin distance automatic adjustments. A similar architecture using Escrst™ is shown in Exhibit 7-9. The Escrst™ modularity makes it quicker to build and incrementally improve robustness in designs for new systems and retrofit into existing systems. A different architecture called Multiflex™ (Exhibit 7-10) has a box frame instead of the c-frame. The operator controls from the floor level, which permits the system to operate at greater accelerations and velocities than before. The added rigidity enhances the positional accuracy. Multiflex II™ in Exhibit 7-11 is the same design with the addition of an inner c-frame which allows for access in smaller diameter tubes, particularly regional jet fuselages. The Multiflex™ architecture can be used for fuselage and the regional jet wing automatic assembly market. Exhibit 7-12 shows the end effectors traversing on rail mounted linear motors of a frame rotating around a large fuselage section joining. This architecture substitutes for the expensive and maintenance intensive ABAT. Exhibit 7-13 shows a traditional wing riveter architecture with the operator riding on the platform using Escrst™. For very large wings envisioned for the A3XX, a vertical AFS with flexible fixturing may be used; the operator is on the floor (Exhibit 7-14). Also, the vertical architecture in a shorter version can be used for spar assembly. Quotations to BAe Airbus for the Escrst™ vertical wing systems with flexible fixturing and retrofits of Escrst™ to their old Gemcor hydraulic wing fastening systems have been made.

Supply Chain Implications

The modularity exhibited by the Escrst™ product family makes it particularly easy to separate the manufacture of existing modular designs anywhere in the world with minimal risk to final integration at the customer's facility. Further, foreseen extensibility of the product family can be accomplished in a design and build manner with merely the specification of a module being competitively bid and the best offer contract awarded. For technological and competitive advantage control, the end effectors (heads) and the controls, especially the software, are kept in-house.

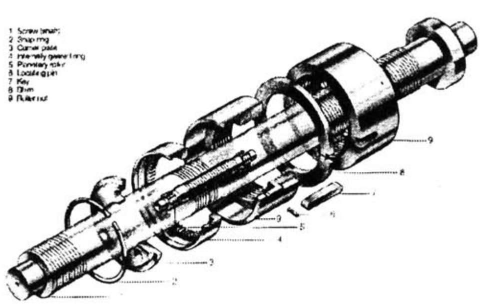
Safety, simplicity of design, simplicity of manufacturing, reliability, ease-of-use, and elements of the design are attributes of the modular Escrst™ architecture, which make the product competitively superior. Escrst™ provides value, in the form of function that is intended to bring utility and pleasure to the user, along with a lower cost. (See Exhibit 7-9) The first seeds have been planted towards achieving the goal of creating a sustaining positive EVA.

Exhibit 7-8
Current Architecture (upper) and New Platform and Modular Design (lower)

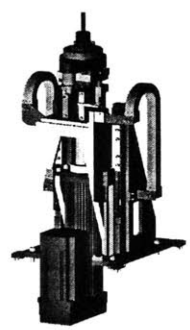


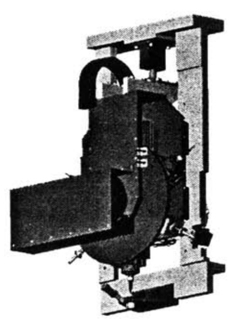
The escrst Platform

ESCRST™ Platforms and Modules

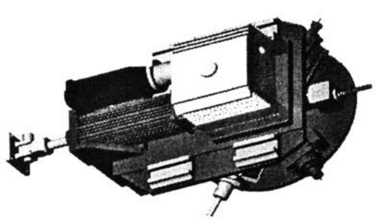


Planetary Roller Screw





ESCRST™ Rotary Head Platform



Different Concept Forms of the ESCRST™ Product Family with Extensibility

Exhibit 7-9

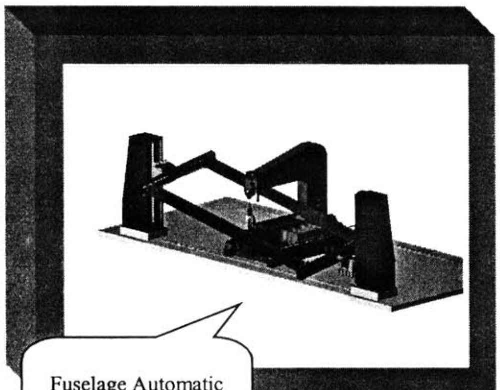


Exhibit 7-10

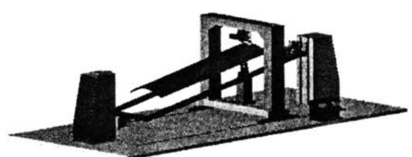


Exhibit 7-11

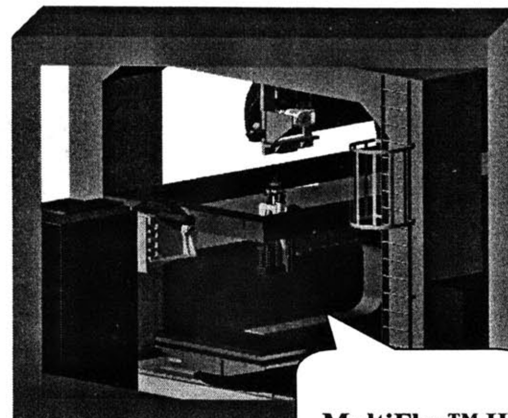


Exhibit 7-12

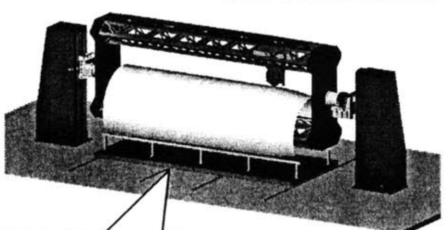


Exhibit 7-13

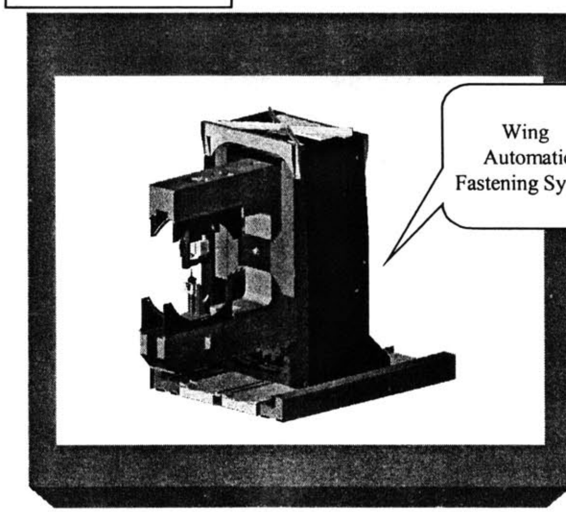
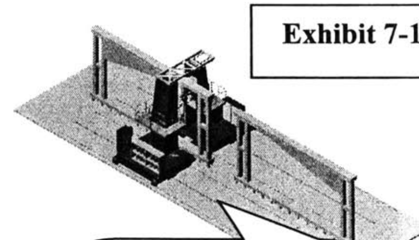


Exhibit 7-14



Section 8

Building a Product Development Organization

Product Development Process Improvements

Although the Escrst™ project covers a single case of product development, it is the intention to extend this application as a model to provide a new and improved product development process which can be replicated time after time by Gemcor.

Gemcor has been experiencing a product development cycle of approximately two to three years. It is recognized that by applying best practices of systems engineering, there is ample opportunity for cost reduction, time-to-market improvement, and robustness enhancement by a superior systems architectural concept design. The current product development process is over 30 years old. This section will demonstrate how to accomplish a substantial reduction in product development cost and production time by incorporating systems engineering best practices, including application of current information technologies (IT), re-grouping of functions to increase concurrent engineering processes, the use of simulation, and digital modeling and computer aided manufacturing (CAM) technologies. Investors require a rate of return greater than their cost of capital of 15 percent and actually desire 20 percent because of assumed riskiness attached to this company's business. The required rate of return on investment will be obtained by new products possessing sustaining competitive advantage supported by strong service support. (See Section 9 describing the system dynamics of sustaining positive growth of the firm.) It is assumed the normal product life cycle will follow an S-curve shape or pattern of sales and production and decline after a point of maturity and/or product/technology substitution.

The company has developed a list of organizational functions and tasks[75] to be accomplished within the product development cycle. (See Exhibit 8-1) There are ten (10) organizational entities now involved: enterprise management, finance, marketing, sales, program management, product development, engineering, manufacturing operations, spare parts, and services. Additionally the relationships were identified as well as the relative strength of these relationships among the functional tasks. These tasks were put into the DSM N^2 optimization software product[76], which highlighted the opportunities for grouping of functions and tasks which had strong information exchange bond (coupling strength) connections, in addition to opportunities for concurrent or parallel activities. Both the functional groupings and parallelism of activities were critical to the significant improvement of product development cycle time, time-to-market. (See Exhibit 8-2) Running the DSM optimization algorithm created an optimized N^2 diagram. In this optimized task organized manner, "non-value added" time can be significantly reduced. (See Exhibit 8-3) The predecessors identified from this optimization were put into a PERT chart network diagram to discern the possible time improvement due to grouping highly dependent organizational functions and concurrency of activities. [77] (See Exhibit 8-4)

As aforementioned, one limited scope but valuable objective was to reduce the time-to-market and product development time for this current project, but a more powerful process development improvement was to restructure the entire corporation to achieve faster and lower cost new product developments for all future programs. Therefore, the organizational structure of the Company is to

[75] These tasks have been adapted in part from Systems Engineering, MIT, C. Boppe, 1999.
[76] Design Matrix Structure Excel Macro downloaded from the MIT DSM website, http://web.mit.edu/dsm/macros.htm; also, Systems Analysis and Management: Structure, Strategy, and Design, D. Steward, Petrocelli Books, 1981.
[77] The critical path of tasks and schedule was calculated using MSProject98.

provide not only a better investment return for this case as a significant project, but also create opportunities for improved future market/product developments. To accomplish these improvement requirements, the author designed a market centered multiproduct matrix organization to create closeness of the program management, engineering technical compliance assurance, organizational functional responsibilities, and product development in a concurrent process engineering environment. (See Exhibit 8-8)[78] The new organizational structure is philosophically based on design for manufacturing and assembly (DFMA) practices of reducing parts, designing assembly platforms, component modularity, standardization of components where possible, and quick connect "bolt on" modular assemblies.

An information technology system was designed to foster asynchronous as well as synchronous communication to reduce the need for and time spent in meetings, which delay completion of tasks, and to encourage collaborative (CAD) engineering design and other application sharing tools to reduce or eliminate time delays between functions – reduce non-value added time. Digital document and workflow management software will be used to route and share required information from one functional group to another for collaborative or sequential process workflow and approval authorizations. Information technology, such as Lotus Notes work flow management and an SAP equivalent[79] enterprise IT system, will be used to as large extent as possible to eliminate manual routine procedures.

All product design is top down driven and bottom up designed using solid digital modeling (CAD) for ease of cross functional, integrated product team (IPT) communications, design development and reviews for improvements, and functional discipline "buy in" for schedule and budgetary adherence. Simulation will be done under the control of the project engineer and his/her IPT to assure compliance to the technical requirements and technical specifications. The product data management system (PDM) is in a CAD/CAE/CAM[80] workflow environment. The program manager will be teamed with the project engineer to be a "heavy" business and technical control manager over the functionaries in the matrix organization. The program manager reports to the total enterprise management.

Of the 81 tasks it has been assumed that each task takes approximately one week to complete with an average cost of $19,230 per year. This equates to a design development activity cost of $1 million per year. The sequential tasks are executed one time but all those tasks with feedback circuits, tasks 11 through 13, 20 through 32, and 45 through 80, are executed at least twice. These task-weeks add up to 133. Time delays, design inefficiency, and design costs accrue each time information flows across any of the 10 organizational boundaries. There are 75 flows across boundaries which add 150 days to the 931 days (133*7) for a total of 1081 days or approximately three years. In the PERT network, all tasks were given a one week duration which was assumed to be five work days with weekends and normal holidays excluded, but which could be available for recovery time if the product development fell behind schedule.[81] Of the savings in time and dollars for parallel activity improvements only 50 percent credit has been taken. By incorporating product data management and information technologies and by utilization of the aforementioned matrix organization, the 50 percent lag in realizing time-to-market improvement benefits could the reduced to a 25 percent lag.

Using the DSM tool, the feedback circuits in the N^2 diagram are considered as parallel, concurrent activities. (See PERT/Gantt Chart Exhibit 8-4 with predecessors developed in DSM and feedback loops

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[78] Adopted from organizational concepts expressed in Thinking Beyond Lean: How Multi-Project Management Is Transforming Product Development at Toyota and Other Companies, Michael A. Cusumano and Kentaro Nobeoka, Simon & Schuster, 1998.
[79] Called Made2Manage, http://www.made2manage.com
[80] CAE is computer aided engineering and is an integrated CAD modular system within as CATIA for CAD/CAE/CAM and digital product simulations using Deneb.
[81] The critical path of tasks and schedule was calculated using MSProject98.

treated as concurrent activities.) In the first scenario, all tasks have a single pass which resulted in a product development completion date of 10-20-2000 (with an assumed start date of 1-1-2000) or 0.80 years for the development time. After making concurrent activities go through the required two passes per task, the result was 0.88 years for the development time. However, an assumption stated that the time saved 2.08 (2.96 - 0.88) years should be considered for only 50 percent of its worth. So, after adding 50 percent of the savings back to the calculation, the total development time will take 1.92 years. Given the new matrix organization described already and the information technology improvements, it is anticipated that the 50 percent time lag in improving the product development process time can be reduced to 25 percent. The product development time is now reduced to 1.4 years.

Additional improvements can be accomplished. It is assumed that quality function deployment (QFD) market/ product development techniques were used in part to determine the target price and resultant target cost. Further, by adding perceived value to the product and using superior concept simulation for risk reduction, there will be superior perception by the customer compared to competition. The price has been increased by 7% to $3.2 million in the best practices model due to the enhanced value assumed to be recognized by the customers. Both the application of best practices of systems engineering modeling and the new organization and IT improvements have increased the product's value and reduced its cost. Also, a branding effort to improve the customer perceived value especially for prestige items will be introduced.

A final consideration is the risk reduction which results from enhanced collective organizational thinking, customer participation in product design, systems' simulation modeling, FMEA,[82] fault coverage and design of experiments tests. These all combine to reduce project and product risk in consideration of technical, financial and schedule terms. This leads to a cost of capital risk reduction perceived by the investors by 4% (20% -16%) to a 2% margin. This final scenario net present value (NPV) is $32.4 million. (See NPV, Cash Flows and Calculation sheets in Exhibits 8-5, 8-6 and 8-7 respectively)

The scenarios vary in time from 0.88 years with 50% improvement delay for a total time of 1.92 years to 1.4 years if a more realistic 25% improvement delay is experienced. NPV turns positive in 6 and 3 years respectively. Total net cash flow generated $70.5 million for the baseline and $108.8 million for the improved product development practices case (not including the time value of money). The time and costs improvement results in a positive NPV starting in year 6 with a total NPV of $11.7 million for the expected 15-year product life cycle period. For the use of best practices, a positive NPV of $32.4 million starts in year 3. Additionally it is noteworthy that the internal rates of return (IRR) are 51% for the past practice and 110% anticipated for the use of best practices. The reduction in time to develop products and the use of best practices serve to decrease the $3 million investment to approximately $838,000.

As can be seen, the product development process improvements are dramatic using systems engineering best practices and organizational improvements to blend together functions and task activity concurrency as developed with the use of the DSM N^2 optimization tool and PERT network diagramming for critical path calculations.

Teams, Group Incentivization and Determining Team Division for Product Development

With respect to the new organizational structure, there are several concurrently operating Design-Build teams planned. The business teams should be thought of as a business microcosm, or perhaps better stated, a micro-business. They are guided by vision and mission, goals preferably creating urgency, and by guiding principles. The team's focus should be on customers. These are the same or similar motivational guidelines for alignment of the entire organization in which the teams are connected.

[82] FMEA is failure mode effects analysis.

It is advised that status differences be minimized, that team leaders work for the team (servant – leader), and that diversity be promoted to avoid groupthink. In relating teams to S→O→R (S_timulus/ incentive→O_rganism/ employee→R_esponse/ performance), if some O's are in conflict with others on the team, individual and team frustration can arise. The collective team O must be in alignment for team effectivity. The team leader should have the ability to create mutual respect among the team associates, assure the job gets done and that problems are solved, and to be a boundary manager.[83] (See Figure 8.1)

The teams will be goals oriented; therefore, it is important that the goals be clearly specified. Remuneration should also be tied to these goals; pecuniary or non-pecuniary incentives can be used. Incentives should be awarded as soon as the goal is achieved, and if goals are not achieved, the team should be clearly informed of the lack of results. The team should be allowed a learning period in order for the team to understand the drivers to success of their goals and mission. It is very likely that a heuristic process will be necessary to find the right, efficient means to achieving the goals. To help stimulate goal/reward achievement, an excellent information system, particularly a feedback loop to the team with appropriate measurables closely tied to the goal, must be provided.

Teams are not islands but are themselves sub-sets of the entire network of the organizational system. Boundary management for information flow to and from teams is essential for team success and total organizational success. (See Figure 8.2) There need to be threads in a network tying all teams to the overall vision, mission, values, goals and guiding principles of the entire organization. The genius in this process is writing and communicating mission – vision, values, goals and guiding principles into a very few simple images and concepts which convey a very powerful motivational message and which serve to initiate complex sets of dynamics to maintain alignment.

Earnings before interest and taxes (EBIT) goals, general profit type goals, and general profit-sharing frequently have no clear, direct relationship from the employee's viewpoint between his work performance and the company's overall success. Teams can have a powerful group cohesiveness and success orientation when their incentive system is highly related to a rewards system closely timed to actual achievement. The learning process of the team still requires feedback from appropriate measures or trends of attainment vs. non-attainment in order to be able to properly act in the direction of the goals.

Group incentive plans should be implemented in order to increase productivity and employee cooperation. If teams are directed to work toward a goal together, then they must be rewarded for their collective effort. If only the leader or highest performer is recognized, the group is apt to lose motivation, and teamwork is not being reinforced. Group incentives can also serve to reduce rivalry by promoting cooperation and concern for the unit's overall performance. Sometimes the formation of a team in itself acts as an incentive by giving members the power to make their own decisions and manage their own work activities, enhancing self-actualization needs. [84]

Teams are analogous to modules in software architecture. The cleavage or division point for creating a team should be based on minimizing the information passed and received from other teams/ groups and preserving maximum interaction within the teams by combining functions and tasks which have substantial interaction. Using products such as DSM, the coupling strength of communication and task dependencies can be analyzed to facilitate combining of tasks and functions into teams. The cleavage plane of teams should follow the architectural structure of the product and the upstream and downstream influences on the product development. (See Figure 8.3 showing teams utilized to develop Escrst™).

- "Products (form) and teams decompose in similar ways and relationships are fundamental

[83] Leading Self-Directed Work Teams, Kimball Fisher, 1993, McGraw-Hill
[84] 1001 Ways to Reward Employees, Bob Nelson, Workman Publishing, NY 1994.

- Goals-function-form decomposition coupling most fundamental in architecture
- Decomposition drives integration, flexibility and management of complexity"[85]
- "Team should be divided to reflect dominant cleavage (form, function, etc.)
- Team/form should be divided so high bandwidth iteration/communication occurs within teams (Eppinger)
- Form should be partitioned to allow maximum concurrency
- Form should be decomposed so that make/buy decisions are easily made
- Form should be decomposed so that teams are clearly accountable
- Every 'level' is based on principle
- Consists of number and plane
- Should reflect entire holistic view of product-process (downstream implicit in principles)
- Should focus on the most critical issues"[86]

The teams may have different life spans depending on their assigned tasks and goals to accomplish.

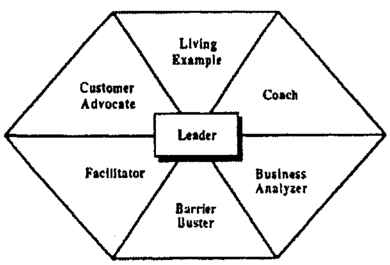


Figure 8.1 Team Leader as Boundary Manager

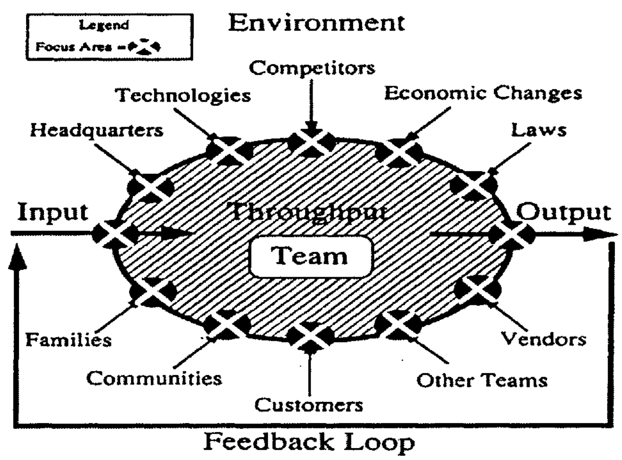


Figure 8.2 Information Feedback Loop and Boundary Management Conditions

New Product/ Market Matrix Organization Design

In part from this DSM analysis the organization chart was designed.[87] The cleaves for team/ functional groups are the functional abstractions in the Exhibit 7-6 of the automatic fastening system. Note that the organization chart shows the team and functions cleaved. Not only were these cleaves determined by the AFS functional abstraction, but also the communication coupling chunks were determined in part using the DSM. The N^2 optimization diagram and readings led us to develop the market centered multiproduct matrix organization.

[85] E. Crawley, Class Lecture, 11-12-99, p. 39.
[86] Ibid. p. 62-63.
[87] See Exhibit 8-5.

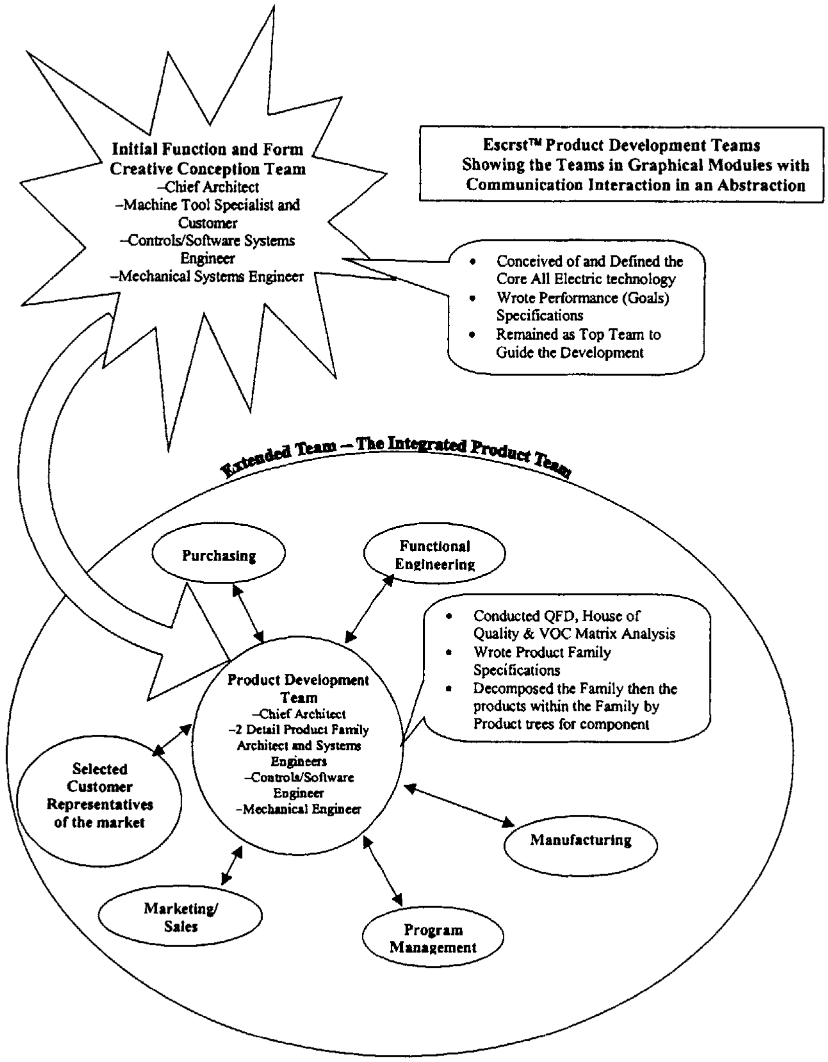


Figure 8.3 Escrst™ Product Development Teams

The new organization chart shown in Exhibit 8-8 groups the tasks and functions in different zones of accountability, control and responsibility. All 81 tasks have been assigned in the organization chart represented by their closeness of feedback and rapidity of interaction, as indicated in the optimized DSM. The functional groups are now collocated to encourage interaction and communication. The matrix form of organization permits functional specialization as well as knowledge in learning growth and transfer within the functional specialties. It also permits utilization of the functions across multiple product lines which breeds core competencies and core technological know-how. It stimulates design and use of common platforms among different product lines where possible. Scheduling of personnel in each function to support product line development requires a continuous resource loading balancing process. There is intentional functional overlap of responsibilities among certain groups. The designated product family architect will usually come out of the product development group as a natural career path extension. This person can now become the product line engineer or the product line program manager. Typically to better assure paradigm shifts, it is wise to hire a product architect from a different field to bring new perspectives and ideas to the product development process. This approach may cause resentment among current employees, which can make life very difficult for the new product architect. It is essential that the CEO, other top management, and the Board of Directors give complete support to the product architect and the product development team to encourage and protect them from internal counter creative and counterproductive forces. The check sheet in Exhibit 8-9 "Framework of Comprehensive Upstream Considerations before Beginning the Architecting Process (Function-Concept-Form)" should be especially useful to the enterprise management, the product architecture team, and the product line heavy manager and engineer to assure adherence to the best practices. It may be noted that the CEO plays a most significant role in fostering, promoting, encouraging, stimulating, internally and externally selling new product developments since these are the seeds of sustainable superior profitability, corporate growth, and diversification. The product development architecting and process must be orchestrated by the CEO as one of his or her primary responsibilities to the continued welfare of the enterprise.

A list of 81 essential tasks in product development was devised and then after a DSM optimization the tasks were grouped in the manner shown below to serve as the construct for developing a new product market organizational structure. Each task was assigned to a group by its relationship to the group's accountability, responsibility and need for functional controllability. The DSM demonstrated the sequential and parallel activities very well, which was then used to minimize the product development time by using MSProject. With the results of these two grouping methods, creative judgment then was applied to design the Gemcor organizational structure.

Task	The Enterprise Management Is Responsible for:
6	Authorize Program Definition Phase
10	Conduct Market Requirements Review
17	Conduct Program Review
21	Select Baseline Configuration
31	Authorize Configuration Definition Phase
42	Conduct a Preliminary Design Review
59	Conduct Final Preliminary Design Review
72	Conduct Program Plan Review
81	Commit to Production

The Group Titled Marketing, Sales and Finance Functions Is Responsible for:

1	Perform Market Evaluation
7	Develop Market Requirements and Pricing Objectives
9	Perform Market Sensitivity Analysis
28	Update Market Evaluation
2	Develop Program Strategy
8	Define Mission Requirements
12	Perform Competitor Analysis
18	Determined Customer or Commonality/Compatibility
29	Update Program Strategy
81	Commit to Production

The Product Line Heavy Manager and Engineer are Responsible for:

15	Develop Preliminary Program Plans
16	Perform Risk Assessment
19	Prepare for Initial Customer Contracts
20	Approve Market Analysis
22	Contact Primary Customers
23	Define Designer Requirements and Objectives
33	Release Program Procedures and Ground Rules
34	Establish Configuration Management Plan

40 Update Risk Analysis
70 Evaluate Preliminary Design Program Vs. Plans
81 Commit to Production

The Functional Engineering Group Is Responsible for:
6 Authorize Program Definition Phase
10 Conduct Market Requirements Review
17 Conduct Program Review
21 Select Baseline Configuration
31 Authorize Configuration Definition Phase
42 Conduct Preliminary Design Review
59 Conduct Final Preliminary Design Review
72 Conduct Program Plan Review

The Sales Group Is Responsible for:
43 Update Marketing/Sales Analysis
74 Contact Secondary Customers
75 Check Primary Customers
81 Commit to Production

The Finance Group Is Responsible for:
24 Develop Alternative Configurations
66 Develop Subsystem Level Cost Estimates
67 Develop System Level Cost Estimate and Design Cost
68 Estimate Development Testing Cost
81 Commit to Production

The Manufacturing Group Is Responsible for:
37 Perform Producibility Analysis of Alternatives
61 Perform Subsystem Level Producibility Analysis
63 Update Manufacturing and Procurement Plans
64 Update Manufacturing and Procurement Risks
77 Develop Manufacturing Processes
81 Commit to Production

The Quality (TQM) Group Is Responsible for:
57 Develop Preliminary Product Management Plan
60 Identify Long Lead in High-risk Items
71 Identify Unproven Processes and Materials
73 Assess Test Results of Unproven Processes
81 Commit to Production

The Customer Service and Spare Parts Group Is Responsible for:
41 Analyze Product Supportability
48 Develop Product Support Plans
65 Update Product Support Analysis
81 Commit to Production

The Product Development Center Is Responsible for:
3 Develop Potential Product Concept Definitions
4 Define Program Definition Phase Plan

11 Develop Configuration
13 Perform Configuration Trade Studies
25 Develop Configuration Phase Program Plan
26 Establish Comparison Evaluation Criteria
27 Evaluate Alternative Configurations
30 Assess Product Compatibility and Commonality
32 Perform Configuration Developmental Testing
35 Extend Designer Requirements and Objectives
36 Conduct Design Trade Studies of Alternatives
38 Develop Configuration Descriptions and Layouts
39 Develop System Level Weight Estimates
44 Complete Initial Some-Scale Tests
45 Complete Second Series Sub-Scale Tests
46 Define Initial Loads
47 Define Control Characteristics
49 Establish Design Data and Test Requirements
50 Establish External Contours
51 Establish Preliminary Power Definition
52 Estimate Preliminary Loads
54 Update Performance Based on Testing Results
55 Conduct Subsystem Level Design Trade Studies
58 Develop Subsystem Level Weight Estimates
62 Update Design Data
69 Evaluate Against Competitor Products
76 Design and Development of High-risk/Long Lead Items
78 Develop Preliminary Digital Mockup
79 Develop Risk Evaluation and Contingency Plan
80 Evaluate Development Test Progress
81 Commit to Production

The Evolution and Improvement of Gemcor's Organizational Structure

Gemcor's previous organization structure had inherent weaknesses, one of which was the basic lack of accountability. Only the President was accountable. The project managers had less authority than functional managers and had little authority over technical compliance of projects. Each project was managed rather independently, which inhibited learning being passed along from project to project both in sharing of technology and management best practices. Also, there was a lack of specialization of functional requirements within the engineering group and product builders.

The time arrived for Gemcor to evolve its project management system, which it had clearly outgrown, into what can be described as a Multiproject center, product development matrix organization. (See Exhibit 8-8) It was proposed that project managers become "heavy" managers with micro-business accountability. The term micro-business referred to the condition in which a project would have all the elements of a business in its structure. Further, the project engineer now reports directly to the project manager and not to any other functional group. By this organizational design, all business and technical compliance accountabilities are in one focal point.

The Engineering and Manufacturing groups moved to organize themselves into functional design and build specializations. For example, there would be heads design, positioners design, controls design and software design in Engineering functional groups, and in Manufacturing, there would be heads build, console build, and positioner build specialist groups. The program manager and project engineer are now positioned within a center and accountable for it. The center can be defined as a product type, such as, Wings, automated spar assembly tool (ASAT), Fuselage, automatic body assembly tool (ABAT), and Military. Another type of center organization structure could be designated as Boeing for one, and Airbus as another to create customer centers.

It is assumed that each project manager and project engineer would manage up to five projects in different stages of development simultaneously. At the end of the project, the center does not disband; the project manager and project engineer stay together to give continuity to the center. The heavy project manager and project engineer combination will lead a top-down design methodology rather than a mostly bottom up design, which is current practice. Greater contract and technical compliance is expected to be obtained.

Internal discussions about the strengths and weaknesses of this evolved organizational design have raised the necessity for functional groups and cross-functional capacity planning. Several very strong, well-managed micro-business centers could vie for the same limited resources at the same time, causing conflicts. Therefore, it is a requirement that a strong capacity planning system exist both within each functional group and cross functionally for resource balancing and in order to support this multi-project organization.

The product development center is not directly connected to the other micro-business centers in order that it specialize in longer-term product developments, such as new head designs and processes which may take a longer time to develop than the normal duration of a project. Also, technology risks need to be assessed and prototypes built and thoroughly tested to prevent adding risk to projects during technology transfer. One of the endeavors of the product development center is to be proactive in the functional design process to encourage the development of product lines and their sub-elements, utilizing well designed modules that provide both flexibility for a customer application and their desired options while, at the same time, providing standard repeatable build modules. With this capability, sales will use a configurator to define suitable systems to meet customer requirements in aerostructure assembly. Over time, the PDC would like to see 80% of the engineers work on new products and product lines as opposed to the very small percentage that is being spent in this area today.

In an ideal world, the positioning systems will accommodate hydraulic, rotary and linear-transfer electric heads. The company wants to emphasize technology transfer and component commonality across the product line, just as the automotive industry uses common platforms, engines, hydraulic, electric and other components across their product lines in luxury, non-luxury and recreational vehicles. In addition to technology transfer, there is a task duplication reduction.

In Gemcor's case, heads can be transferred across the product line. Software, the core portion of the operating code and HMI screens, can be transferred. In the electrical area operators consoles can be defined with a few designs; motors can be sized in standard models and likewise amplifiers and gearboxes. Additionally, feed systems can be standardized.

Conclusion

Using the DSM analytical tool, MSProject, and good creativity and judgment, savings have been created by reorganizing the design development process tasks to minimize rework and optimize information flow. Emphasis on concurrent engineering, making tasks parallel as much as possible, has reduced the time and cost. Restructuring the organization has reduced the number of organizational boundaries, thereby minimizing the losses incurred by crossing boundary planes. By means of these organizational changes described in this section, the time of development has been significantly reduced as well as the cost from $3 million to $838,000 per product development.

Exhibit 8-1 Tasks Presorted and Sorted by Organizational Function

1	Perform Market Evaluation	PERF_MARKET_EVAL	Marketing
2	Develop Program Strategy	DEV_PRGRM_STRAT	Marketing & Prod. Dvmt
3	Develop Potential Product Concept Definitions	DEV_CONCEPT_DEFS	Product Development
4	Define Program Definition Phase Plan	DEF_PRGRM_PLAN	Product Development
5	Define Technology Development Requirements	ID_TECH_DVMT_REQ	Prod. Dvmt. & Engineering
6	Authorize Program Definition Phase	AUTH_DEF_PHASE	Enterprise Management
7	Develop Market Requirements and Pricing Objectives	DEVLP_PRICNG_OBJ	Marketing
8	Define Mission Requirements	DEF_MISSION_RQMTS	Marketing & Prod. Dvmt.
9	Perform Market Sensitivity Analysis	PERF_MRKT_ANALYS	Marketing
10	Conduct Market Requirements Review	MRKT_RQMTS_REV	Enterprise Management
11	Develop Configuration	DEVELOP_CONFIG	Product Development
12	Perform Competitive Analysis	PERF_COMPET_ANAL	Marketing & Prod. Dvmt.
13	Perform Configuration Trade Studies	PERF_TRADE_STUD	Product Development
14	Assess Current IR&D Applicability	EVAL_IRnD_APPLIC	Prod. Dvmt. & Engineering
15	Develop Preliminary Program Plans	DVP_PRE_PRG-PLN	Finance & Program Management
16	Perform Risk Assessment	PERF_RISK_ASSMT	Program Management
17	Conduct Program Review	PROGRAM_REVIEW	Enterprise Management
18	Determine Customer Commonality/Compatability	DET_CUST_CMnCMP	Marketing & Prod. Dvmt.
19	Prepare for Initial Customer Contracts	PREP_CUST_CNTCTS	Program Management
20	Approve Market Analysis	APRV_MRKT_ANAL	Program Management
21	Select Baseline Configuration	SLCT_BSLN_CONFIG	Enterprise Management
22	Contact Primary Customers	CONTCT_PRM_CUST	Program Management
23	Define Design Requirements and Objectives	DEF_RQMTS_OBJTVS	Program Management
24	Develop Alternative Configurations	DVP_ ALT_CONFIGS	Product Development & Finance
25	Develop Configuration Phase Program Plan	DVP_CONFIG_PRGM	Product Development
26	Establish Comparison Evaluation Criteria	EST_EVAL_CRITER	Product Development
27	Evaluate Alternative Configurations	EVAL_ALT_CONFIGS	Product Development
28	Update Market Evaluation	UPDT_MRKT_EVAL	Marketing
29	Update Program Strategy	UPDT_PRGM_STRAT	Marketing & Prod. Dvmt.
30	Assess Product Compatibility and Commonality	EVAL_PROD_CMnCMP	Product Development
31	Authorize Configuration Definition Phase	AUTH_CNFG_DEF_PH	Enterprise Management
32	Perform Configuration Developmental Testing	CONFIG_DVMT_TSTG	Product Development
33	Release Program Procedures and Groundrules	REL_PRCDnGRDRLS	Program Management
34	Establish Configuration Management Plan	EST_CONFIG_PLAN	Program Management
35	Extend Design Requirements and Objectives	EX_DES_RQMTnOBJS	Product Development
36	Conduct Design Trade Studies of Alternates	ALT_TRADE_STDYS	Product Development
37	Perform Producibility Analysis of Alternates	ALT_PRODUC_ANAL	Manufacturing Operations
38	Develop Configuration Descriptions and Layouts	DVP_CONFG_LYOUT	Product Development
39	Develop System Level Weight Estimates	DVP_SYSLV_WT_EST	Product Development
40	Update Risk Analysis	UPDAT_RISK_ANAL	Program Management
41	Analyze Product Supportability	PROD_SUPRT_ANAL	Prod. Dvmt. & Customer Service
42	Conduct Preliminary Design Review	PRELM_DES_REVU	Enterprise Management
43	Update Marketing/Sales Analysis	UPDT_MKTnSL_ANAL	Sales & Marketing
44	Complete Initial Sub-Scale Tests	COMPL_SCAL_TEST1	Product Development
45	Complete Second Series Sub-Scale Tests	COMPL_SCAL_TEST2	Product Development
46	Define Initial Loads	DEF_INIT_LOADS	Product Development
47	Define Control Characteristics	DEF_CNTRL_CHAR	Product Development
48	Develop Product Support Plans	DEV_PRD_SPRT_PLN	Product Development & Customer Service
49	Establish Design Data and Test Requirements	EST_DSDTAnTST_RQ	Product Development
50	Establish External Geometry	EST_EXTRNL_CNTRS	Product Development
51	Establish Preliminary Power Package	EST_PRLM_ENG_PKG	Product Development
52	Estimate Preliminary Loads	EST_PRELIM_LOADS	Product Development
53	Perform Subcontractor and Supplier Studies	PERF_SUBCnSPLR_ST	Prod. Dvmt. & Support Operations
54	Update Performance Based on Testing Results	UDT_PRF_BSDN_TSTG	Product Development
55	Conduct Subsystem Level Design Trade Studies	SSYS_DES_TRD_STD	Product Development
56	Develop Detailed Configuration Descriptions	DVP_DET_CNFG_DES	Product Development
57	Develop Preliminary Controls Management Plan	DVP_ENG_MGMT_PLN	Product Development & Support Operations
58	Develop Subsystem Level Weight Estimates	DVP_SSYS_WT_ESTS	Product Development
59	Conduct Final Preliminary Design Review	FNL_PRLM_DES_REV	Enterprise Management
60	Identify Long Lead and High Risk Items	ID_LLDnHIRSK_ITMS	Product Development & Support Operations
61	Perform Subsystem Level Producibility Analysis	DEF_SSYS_PRD_ANL	Manufacturing Operations
62	Update Design Data	UPDT_DESIGN_DATA	Product Development
63	Update Manufacturing and Procurement Plans	UPDT_MFGnPRC_PLN	Manufacturing Operations
64	Update Manufacturing and Procurement Plans	ID_MFGnPRC_RISKS	Manufacturing Operations
65	Update Product Support Analysis	UPDT_PRD_SPRT_ANL	Product Development & Customer Service
66	Develop Subsystem Level Cost Estimates	DVP_SSYS_CST_EST	Finance
67	Develop System Level Cost Estimate and Design Cost	DVP_PRD_DESN_CST	Finance
68	Estimate Development Testing Cost	EST_DVMT_TSTG_CST	Finance
69	Evaluate Against Competitor Products	EVL_COMPET_PRDS	Product Development
70	Evaluate Preliminary Design Program Versus Plans	CMPR_DSN_PRGwPLN	Program Management
71	Identify Unproven Processes and Materials	ID_HIRSK_PRCnMTLS	Product Development & Support Operations
72	Conduct Program Plan Review	PRGM_PLAN_REVIEW	Enterprise Management
73	Assess Test Results on Unproven Processes	CHK_RSK_PRC_TSTS	Product Development & Support Operations
74	Contact Secondary Customers	CONTCT_SEC_CUST	Sales & Marketing
75	Check Primary Customers	CHK_PRM_CUST	Sales & Marketing
76	Design and Development of High Risk/Long Lead Items	HIRSKnLL_DSnDVMT	Product Development
77	Develop Manufacturing Processes	DVP_MFG_PROCS	Manufacturing Operations
78	Develop Preliminary Digital Mockup	DVP_DGTL_MKUP	Product Development
79	Develop Risk Evaluation and Contingency Plan	DVP_RSK_CNTN_PLN	Product Development
80	Evaluate Development Test Progress	EVL_DVMT_TST_PRG	Product Development
81	Commit To Production	COMIT_TO_PRODCTN	Product Development

6	Authorize Program Definition Phase	AUTH_DEF_PHASE	Enterprise Management
10	Conduct Market Requirements Review	MRKT_RQMTS_REV	Enterprise Management
17	Conduct Program Review	PROGRAM_REVIEW	Enterprise Management
21	Select Baseline Configuration	SLCT_BSLN_CONFIG	Enterprise Management
31	Authorize Configuration Definition Phase	AUTH_CNFG_DEF_PH	Enterprise Management
42	Conduct Preliminary Design Review	PRELM_DES_REVU	Enterprise Management
59	Conduct Final Preliminary Design Review	FNL_PRLM_DES_REV	Enterprise Management
72	Conduct Program Plan Review	PRGM_PLAN_REVIEW	Enterprise Management
66	Develop Subsystem Level Cost Estimates	DVP_SSYS_CST_EST	Finance
67	Develop System Level Cost Estimate and Design Cost	DVP_PRD_DESN_CST	Finance
68	Estimate Development Testing Cost	EST_DVMT_TSTG_CST	Finance
15	Develop Preliminary Program Plans	DVP_PRE_PRG-PLN	Finance & Program Management
37	Perform Producibility Analysis of Alternates	ALT_PRODUC_ANAL	Manufacturing Operations
61	Perform Subsystem Level Producibility Analysis	DEF_SSYS_PRD_ANL	Manufacturing Operations
63	Update Manufacturing and Procurement Plans	UPDT_MFGnPRC_PLN	Manufacturing Operations
64	Update Manufacturing and Procurement Plans	ID_MFGnPRC_RISKS	Manufacturing Operations
77	Develop Manufacturing Processes	DVP_MFG_PROCS	Manufacturing Operations
1	Perform Market Evaluation	PERF_MARKET_EVAL	Marketing
7	Develop Market Requirements and Pricing Objectives	DEVLP_PRICNG_OBJ	Marketing
9	Perform Market Sensitivity Analysis	PERF_MRKT_ANALYS	Marketing
28	Update Market Evaluation	UPDT_MRKT_EVAL	Marketing
2	Develop Program Strategy	DEV_PRGRM_STRAT	Marketing & Prod. Dvmt
8	Define Mission Requirements	DEF_MISSION_RQMTS	Marketing & Prod. Dvmt.
12	Perform Competitive Analysis	PERF_COMPET_ANAL	Marketing & Prod. Dvmt.
18	Determine Customer Commonality/Compatability	DET_CUST_CMnCMP	Marketing & Prod. Dvmt
29	Update Program Strategy	UPDT_PRGM_STRAT	Marketing & Prod. Dvmt.
41	Analyze Product Supportability	PROD_SUPRT_ANAL	Prod. Dvmt. & Customer Service
5	Define Technology Development Requirements	ID_TECH_DVMT_REQ	Prod. Dvmt. & Engineering
14	Assess Current IR&D Applicability	EVAL_IRnD_APPLIC	Prod. Dvmt. & Engineering
53	Perform Subcontractor and Supplier Studies	PERF_SUBCnSPLR_ST	Prod. Dvmt. & Support Operations
3	Develop Potential Product Concept Definitions	DEV_CONCEPT_DEFS	Product Development
4	Define Program Definition Phase Plan	DEF_PRGRM_PLAN	Product Development
11	Develop Configuration	DEVELOP_CONFIG	Product Development
13	Perform Configuration Trade Studies	PERF_TRADE_STUD	Product Development
25	Develop Configuration Phase Program Plan	DVP_CONFIG_PRGM	Product Development
26	Establish Comparison Evaluation Criteria	EST_EVAL_CRITER	Product Development
27	Evaluate Alternative Configurations	EVAL_ALT_CONFIGS	Product Development
30	Assess Product Compatibility and Commonality	EVAL_PROD_CMnCMP	Product Development
32	Perform Configuration Developmental Testing	CONFIG_DVMT_TSTG	Product Development
35	Extend Design Requirements and Objectives	EX_DES_RQMTnOBJS	Product Development
36	Conduct Design Trade Studies of Alternates	ALT_TRADE_STDYS	Product Development
38	Develop Configuration Descriptions and Layouts	DVP_CONFG_LYOUT	Product Development
39	Develop System Level Weight Estimates	DVP_SYSLV_WT_EST	Product Development
44	Complete Initial Sub-Scale Tests	COMPL_SCAL_TEST1	Product Development
45	Complete Second Series Sub-Scale Tests	COMPL_SCAL_TEST2	Product Development
46	Define Initial Loads	DEF_INIT_LOADS	Product Development
47	Define Control Characteristics	DEF_CNTRL_CHAR	Product Development
49	Establish Design Data and Test Requirements	EST_DSDTAnTST_RQ	Product Development
50	Establish External Geometry	EST_EXTRNL_CNTRS	Product Development
51	Establish Preliminary Power Package	EST_PRLM_ENG_PKG	Product Development
52	Estimate Preliminary Loads	EST_PRELIM_LOADS	Product Development
54	Update Performance Based on Testing Results	UDT_PRF_BSDN_TSTG	Product Development
55	Conduct Subsystem Level Design Trade Studies	SSYS_DES_TRD_STD	Product Development
56	Develop Detailed Configuration Descriptions	DVP_DET_CNFG_DES	Product Development
58	Develop Subsystem Level Weight Estimates	DVP_SSYS_WT_ESTS	Product Development
62	Update Design Data	UPDT_DESIGN_DATA	Product Development
69	Evaluate Against Competitor Products	EVL_COMPET_PRDS	Product Development
76	Design and Development of High Risk/Long Lead Items	HIRSKnLL_DSnDVMT	Product Development
78	Develop Preliminary Digital Mockup	DVP_DGTL_MKUP	Product Development
79	Develop Risk Evaluation and Contingency Plan	DVP_RSK_CNTN_PLN	Product Development
80	Evaluate Development Test Progress	EVL_DVMT_TST_PRG	Product Development
81	Commit To Production	COMIT_TO_PRODCTN	Product Development
48	Develop Product Support Plans	DEV_PRD_SPRT_PLN	Product Development & Customer Service
65	Update Product Support Analysis	UPDT_PRD_SPRT_ANL	Product Development & Customer Service
24	Develop Alternative Configurations	DVP_ ALT_CONFIGS	Product Development & Finance
57	Develop Preliminary Controls Management Plan	DVP_ENG_MGMT_PLN	Product Development & Support Operations
60	Identify Long Lead and High Risk Items	ID_LLDnHIRSK_ITMS	Product Development & Support Operations
71	Identify Unproven Processes and Materials	ID_HIRSK_PRCnMTLS	Product Development & Support Operations
73	Assess Test Results on Unproven Processes	CHK_RSK_PRC_TSTS	Product Development & Support Operations
16	Perform Risk Assessment	PERF_RISK_ASSMT	Program Management
19	Prepare for Initial Customer Contracts	PREP_CUST_CNTCTS	Program Management
20	Approve Market Analysis	APRV_MRKT_ANAL	Program Management
22	Contact Primary Customers	CONTCT_PRM_CUST	Program Management
23	Define Design Requirements and Objectives	DEF_RQMTS_OBJTVS	Program Management
33	Release Program Procedures and Groundrules	REL_PRCDnGRDRLS	Program Management
34	Establish Configuration Management Plan	EST_CONFIG_PLAN	Program Management
40	Update Risk Analysis	UPDAT_RISK_ANAL	Program Management
70	Evaluate Preliminary Design Program Versus Plans	CMPR_DSN_PRGwPLN	Program Management
43	Update Marketing/Sales Analysis	UPDT_MKTnSL_ANAL	Sales & Marketing
74	Contact Secondary Customers	CONTCT_SEC_CUST	Sales & Marketing
75	Check Primary Customers	CHK_PRM_CUST	Sales & Marketing

Exhibit 8-2 Pre-Optimized Design Matrix Structure

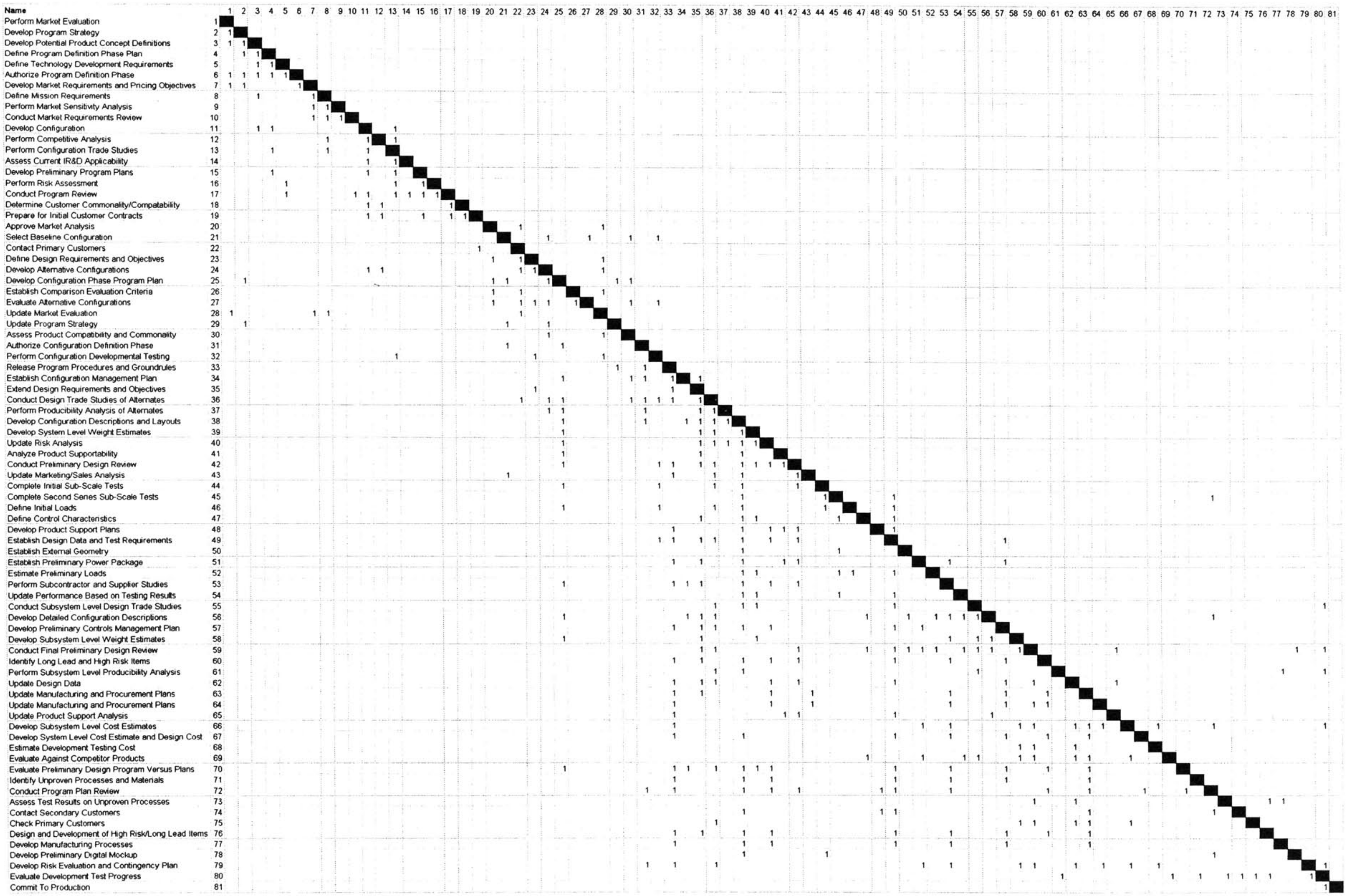


Exhibit 8-3 Optimized Design Matrix Structure

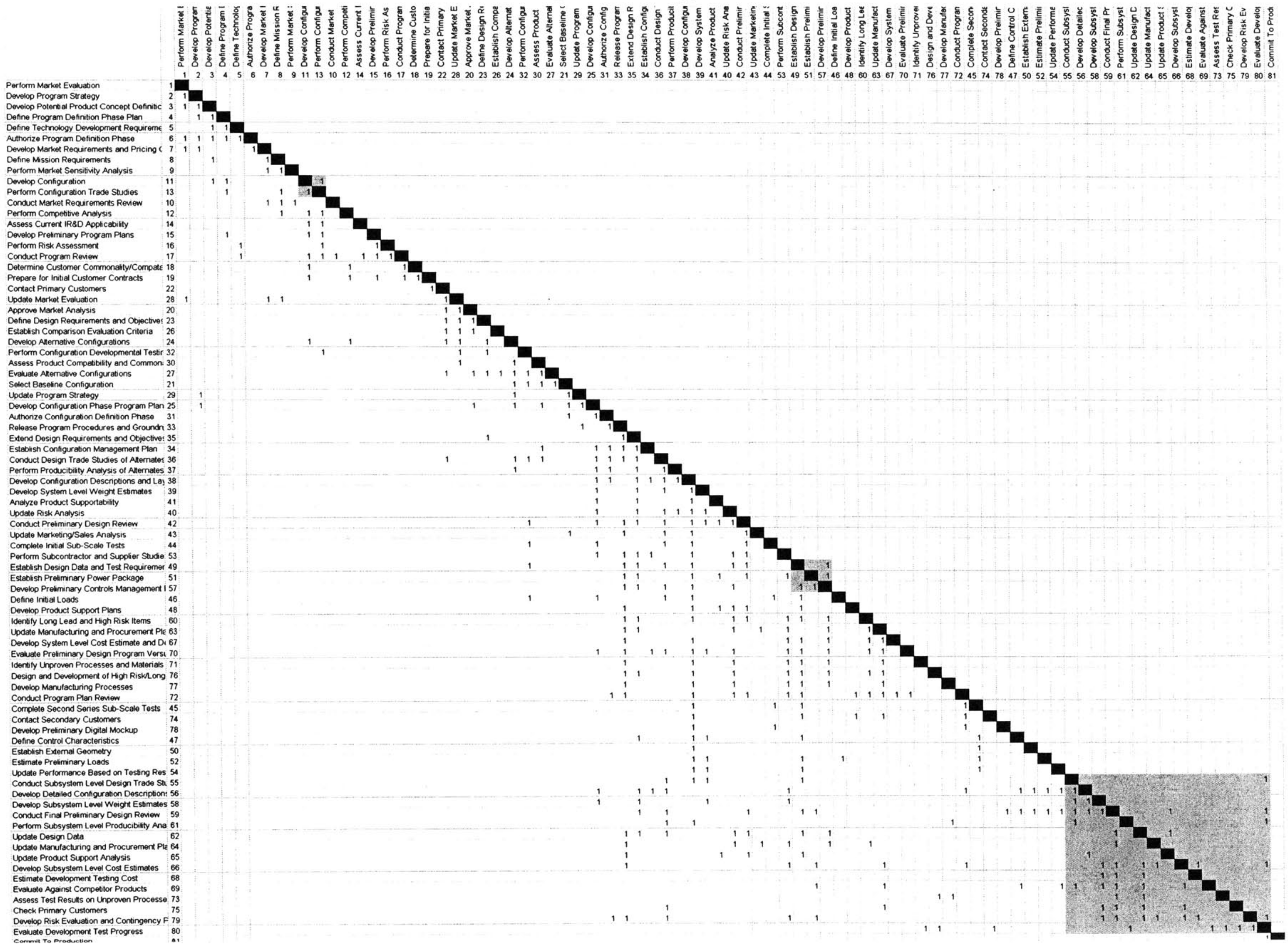


Exhibit 8-4 Pert Chart of the Optimized N^2 Diagram

ID	Task Name	Duration	Start	Finish	Predecessors
1	Perform Market Evaluation	5 days	Mon 1/3/00	Fri 1/7/00	
2	Develop Program Strategy	5 days	Mon 1/10/00	Fri 1/14/00	1
3	Develop Potential Product Concept Definitions	5 days	Mon 1/17/00	Fri 1/21/00	1,2
4	Define Program Definition Phase Plan	5 days	Mon 1/24/00	Fri 1/28/00	2,3
5	Define Technology Development Requirements	5 days	Mon 1/31/00	Fri 2/4/00	3,4
6	Authorize Program Definition Phase	5 days	Mon 2/7/00	Fri 2/11/00	1,2,3,4,5
7	Develop Market Requirements and Pricing Objectives	5 days	Mon 2/14/00	Fri 2/18/00	1,2,6
8	Define Mission Requirements	5 days	Mon 2/21/00	Fri 2/25/00	3,7
9	Perform Market Sensitivity Analysis	5 days	Mon 2/28/00	Fri 3/3/00	7,8
10	Conduct Market Requirements Review	5 days	Mon 3/6/00	Fri 3/10/00	7,8,9
11	Develop Configuration	10 days	Mon 2/28/00	Fri 3/10/00	4,8,3
12	Perform Configuration Trade Studies	10 days	Mon 2/28/00	Fri 3/10/00	4,8,3
13	Perform Competitive Analysis	10 days	Mon 3/13/00	Fri 3/24/00	8,11,12
14	Assess Current IR&D Applicability	5 days	Mon 3/13/00	Fri 3/17/00	11,12
15	Develop Preliminary Program Plans	5 days	Mon 3/13/00	Fri 3/17/00	11,12,4
16	Perform Risk Assessment	5 days	Mon 3/20/00	Fri 3/24/00	12,15,5
17	Conduct Program Review	5 days	Mon 3/27/00	Fri 3/31/00	5,10,11,12,14,15,16
18	Determine Customer Commonality/Compatibility	5 days	Mon 4/3/00	Fri 4/7/00	11,13,17
19	Prepare for Initial Customer Contracts	5 days	Mon 4/10/00	Fri 4/14/00	11,13,15,17,18
20	Contact Primary Customers	5 days	Mon 4/17/00	Fri 4/21/00	19
21	Update Market Evaluation	5 days	Mon 4/24/00	Fri 4/28/00	1,7,8,20
22	Approve Market Analysis	5 days	Mon 5/1/00	Fri 5/5/00	20,21
23	Define Design Requirements and Objectives	5 days	Mon 5/8/00	Fri 5/12/00	20,21,22
24	Develop Alternative Configurations	5 days	Mon 5/15/00	Fri 5/19/00	11,13,20,21,23
25	Assess Product Compatibility and Commonality	5 days	Mon 5/22/00	Fri 5/26/00	21,24
26	Perform Configuration Developmental Testing	5 days	Mon 5/15/00	Fri 5/19/00	12,21,23
27	Establish Comparison Evaluation Criteria	5 days	Mon 5/8/00	Fri 5/12/00	20,21,22
28	Evaluate Alternative Configurations	5 days	Mon 5/29/00	Fri 6/2/00	20,22,23,24,25,26,27
29	Select Baseline Configuration	5 days	Mon 6/5/00	Fri 6/9/00	24,25,26,28
30	Update Program Strategy	5 days	Mon 6/12/00	Fri 6/16/00	2,29,24
31	Develop Configuration Phase Program Plan	5 days	Mon 6/19/00	Fri 6/23/00	2,22,24,25,29,30
32	Authorize Configuration Definition Phase	5 days	Mon 6/26/00	Fri 6/30/00	29,31
33	Release Program Procedures and Groundrules	5 days	Mon 7/3/00	Fri 7/7/00	30,32
34	Extend Design Requirements and Objectives	5 days	Mon 7/10/00	Fri 7/14/00	23,33
35	Conduct Design Trade Studies of Alternates	5 days	Mon 7/17/00	Fri 7/21/00	33,20,24,25,26,31,32,34
36	Perform Producibility Analysis of Alternates	5 days	Mon 7/24/00	Fri 7/28/00	24,31,32,34,35
37	Establish Configuration Management Plan	5 days	Mon 7/17/00	Fri 7/21/00	25,31,32,33,34
38	Develop Configuration Descriptions and Layouts	5 days	Mon 7/31/00	Fri 8/4/00	31,32,34,35,36,37
39	Develop System Level Weight Estimates	5 days	Mon 8/7/00	Fri 8/11/00	31,34,35,38
40	Update Risk Analysis	5 days	Mon 8/14/00	Fri 8/18/00	31,34,35,36,38,39
41	Analyze Product Supportability	5 days	Mon 8/7/00	Fri 8/11/00	31,34,38
42	Conduct Preliminary Design Review	5 days	Mon 8/21/00	Fri 8/25/00	26,31,33,34,35,38,39,40,41
43	Update Marketing/Sales Analysis	5 days	Mon 8/28/00	Fri 9/1/00	29,33,35,38,42
44	Perform Subcontractor and Supplier Studies	5 days	Mon 8/28/00	Fri 9/1/00	31,33,34,37,38,40,42
45	Establish Design Data and Test Requirements	10 days	Mon 9/4/00	Fri 9/15/00	26,33,34,35,38,40,42,41,44
46	Establish Preliminary Power Package	10 days	Mon 9/4/00	Fri 9/15/00	26,33,34,35,38,40,42,41,44
47	Develop Preliminary Controls Management Plan	10 days	Mon 9/4/00	Fri 9/15/00	26,33,34,35,38,40,42,41,44
48	Develop Product Support Plans	5 days	Mon 9/18/00	Fri 9/22/00	33,38,40,41,42,44,45
49	Identify Long Lead and High Risk Items	5 days	Mon 9/18/00	Fri 9/22/00	33,34,38,40,42,44,45,47
50	Update Manufacturing and Procurement Plans	5 days	Mon 9/25/00	Fri 9/29/00	33,34,40,43,44,47,49
51	Identify Unproven Processes and Materials	5 days	Mon 10/2/00	Fri 10/6/00	33,38,40,44,45,47,50
52	Develop System Level Cost Estimate and Design Cost	5 days	Mon 10/2/00	Fri 10/6/00	33,38,44,45,47,49,50
53	Develop Manufacturing Processes	5 days	Mon 10/2/00	Fri 10/6/00	33,38,44,45,47,50
54	Evaluate Preliminary Design Program Versus Plans	5 days	Mon 10/2/00	Fri 10/6/00	33,38,40,44,45,47,49,50,31
55	Conduct Program Plan Review	5 days	Mon 10/9/00	Fri 10/13/00	32,33,38,40,42,44,45,48,49
56	Contact Secondary Customers	5 days	Mon 10/16/00	Fri 10/20/00	38,45,48,50,55
57	Design and Development of High Risk/Long Lead Items	5 days	Mon 10/2/00	Fri 10/6/00	33,34,38,40,44,45,47,49,50
58	Complete Initial Sub-Scale Tests	5 days	Mon 8/28/00	Fri 9/1/00	26,31,35,38,42
59	Develop Preliminary Digital Mockup	5 days	Mon 10/16/00	Fri 10/20/00	38,55,58
60	Complete Second Series Sub-Scale Tests	5 days	Mon 10/16/00	Fri 10/20/00	38,45,55,58
61	Define Control Characteristics	5 days	Mon 10/23/00	Fri 10/27/00	34,38,39,45,60
62	Update Performance Based on Testing Results	5 days	Mon 10/23/00	Fri 10/27/00	38,39,45,60
63	Establish External Geometry	5 days	Mon 10/23/00	Fri 10/27/00	38,60
64	Define Initial Loads	5 days	Mon 9/18/00	Fri 9/22/00	26,31,35,38,45,58
65	Estimate Preliminary Loads	5 days	Mon 10/23/00	Fri 10/27/00	38,39,45,60,64
66	Check Primary Customers	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
67	Evaluate Against Competitor Products	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
68	Develop Subsystem Level Cost Estimates	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
69	Estimate Development Testing Cost	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
70	Update Manufacturing and Procurement Plans	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
71	Update Design Data	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
72	Update Product Support Analysis	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
73	Develop Detailed Configuration Descriptions	10 days	Mon 10/30		
74	Conduct Subsystem Level Design Trade Studies	10 days	Mon 10/30		
75	Perform Subsystem Level Producibility Analysis	10 days	Mon 10/30		
76	Develop Risk Evaluation and Contingency Plan	10 days	Mon 10/30		
77	Evaluate Development Test Progress	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
78	Assess Test Results on Unproven Processes	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
79	Conduct Final Preliminary Design Review	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
80	Develop Subsystem Level Weight Estimates	10 days	Mon 10/30/00	Fri 11/10/00	31,32,33,34,35,37,38,39,40
81	Commit To Production	5 days	Mon 11/13/00	**Fri 11/17/00**	77

The complete list of shared Predecessors for 66-80 is: (31,32,33,34,35,37,38,39, 40,41,42,43,44,45,46,47,49, 50,51,53,55,56,57,59,61,62,63,65)

**Exhibit 8-5 The Past Practice Development Cycle
Using 20% cost of capital**

Baseline Business Case Inputs

Revenues

Price	Price Concessions %
$3,000,000	0%

	Investment Costs	Recurring Costs
Year	Cost Per Year	Cost Per Unit
1	$1,000,000	$1,500,000
2	$1,000,000	
3	$1,000,000	
4	$0	
5	$0	
6	$0	

Project Totals

Investment	$3,000,000
Revenues	$153,000,000
Recurring Costs	$79,500,000
Net Cash Program	**$70,500,000**
Return on Investment	
NPV To Shareholders	**$11,713,221**
Internal Rate of Return	**51%**

Schedules

	Production	Delivery
Yr1	0	0
Yr2	0	0
Yr3	2	0
Yr4	3	2
Yr5	4	3
Yr6	5	4
Yr7	5	5
Yr8	5	5
Yr9	5	5
Yr10	5	5
Yr11	5	5
Yr12	5	5
Yr13	4	5
Yr14	3	4
Yr15	2	3
	53	51

**The Best Practices Development Cycle
Using 16% cost of capital**

Best Practices Product Development Cycle

Revenues

Price	Price Concessions %
$3,200,000	0%

	Investment Costs	Recurring Costs
Year	Cost Per Year	Cost Per Unit
1	$ 838,000	$1,200,000
2	$0	
3	$0	
4	$0	
5	$0	
6	$0	

Project Totals

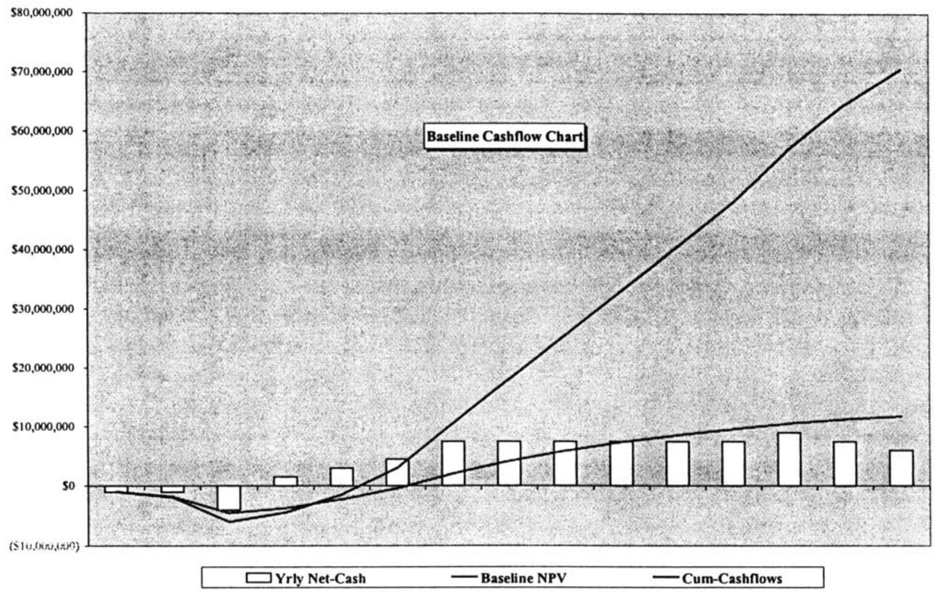
Investment	$838,000
Revenues	$172,800,000
Recurring Costs	$69,600,000
Net Cash Program	**$108,762,000**
Return on Investment	
NPV To Shareholders	**$32,433,539**
Internal Rate of Return	**110%**

Schedules

	Production	Delivery
Yr1	0	0
Yr2	2	0
Yr3	3	2
Yr4	4	3
Yr5	5	4
Yr6	5	5
Yr7	5	5
Yr8	5	5
Yr9	5	5
Yr10	5	5
Yr11	5	5
Yr12	5	5
Yr13	4	5
Yr14	3	4
Yr15	2	3
	58	56

Exhibit 8-6 The Past Practice Development Cycle Cash Flow Using 20% cost of capital

The Best Practices Development Cycle Cash Flow Using 16% cost of capital



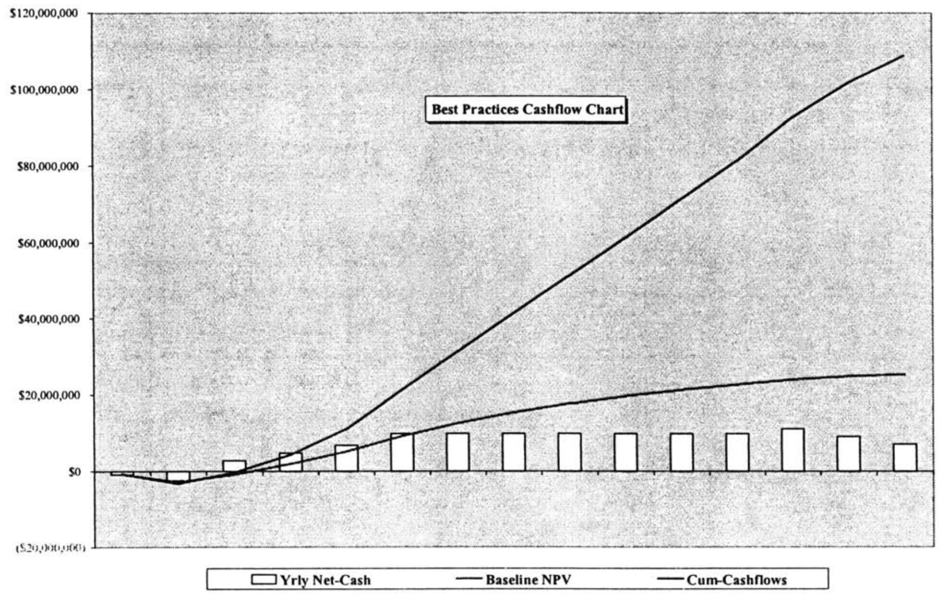


Exhibit 8-7 The Past Practice Development Cycle Calculation Sheet using 20% COC

Timing of Cash Receipt or Expenditure	Cash-In	Cash-Out	Net Cash	Discount Factor	Discounted Cash
Year 1	$0	$1,000,000	($1,000,000)	1.000	($1,000,000)
Year 2	$0	$1,000,000	($1,000,000)	0.833	($833,333)
Year 3	$0	$4,000,000	($4,000,000)	0.694	($2,777,778)
Year 4	$6,000,000	$4,500,000	$1,500,000	0.579	$868,056
Year 5	$9,000,000	$6,000,000	$3,000,000	0.482	$1,446,759
Year 6	$12,000,000	$7,500,000	$4,500,000	0.402	$1,808,449
Year 7	$15,000,000	$7,500,000	$7,500,000	0.335	$2,511,735
Year 8	$15,000,000	$7,500,000	$7,500,000	0.279	$2,093,112
Year 9	$15,000,000	$7,500,000	$7,500,000	0.233	$1,744,260
Year 10	$15,000,000	$7,500,000	$7,500,000	0.194	$1,453,550
Year 11	$15,000,000	$7,500,000	$7,500,000	0.162	$1,211,292
Year 12	$15,000,000	$7,500,000	$7,500,000	0.135	$1,009,410
Year 13	$15,000,000	$6,000,000	$9,000,000	0.112	$1,009,410
Year 14	$12,000,000	$4,500,000	$7,500,000	0.093	$700,979
Year 15	$9,000,000	$3,000,000	$6,000,000	0.078	$467,319
Totals	**$153,000,000**	**$82,500,000**	**$70,500,000**		

Net Present Value (NPV)	$11,713,221
Discounting Rate	20%
Internal Rate of Return (IRR)	51%

Values for Baseline Cashflow Chart

	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	
Yrly Net-Cash	($1,000,000)	($1,000,000)	($4,000,000)	$1,500,000	$3,000,000	$4,500,000	$7,500,000	$7,500,000	
Cum-Cashflows	($1,000,000)	($2,000,000)	($6,000,000)	($4,500,000)	($1,500,000)	$3,000,000	$10,500,000	$18,000,000	
Baseline NPV	($1,000,000)	($1,833,333)	($4,611,111)	($3,743,056)	($2,296,296)	($487,847)	$2,023,888	$4,117,000	

The Best Practices Development Cycle Calculation Sheet using 16% COC

Timing of Cash Receipt or Expenditure	Cash-In	Cash-Out	Net Cash	Discount Factor	Discounted Cash
Year 1	$0	$838,000	($838,000)	1.000	($838,000)
Year 2	$0	$2,400,000	($2,400,000)	0.862	($2,068,966)
Year 3	$6,400,000	$3,600,000	$2,800,000	0.743	$2,080,856
Year 4	$9,600,000	$4,800,000	$4,800,000	0.641	$3,075,157
Year 5	$12,800,000	$6,000,000	$6,800,000	0.552	$3,755,579
Year 6	$16,000,000	$6,000,000	$10,000,000	0.476	$4,761,130
Year 7	$16,000,000	$6,000,000	$10,000,000	0.410	$4,104,423
Year 8	$16,000,000	$6,000,000	$10,000,000	0.354	$3,538,295
Year 9	$16,000,000	$6,000,000	$10,000,000	0.305	$3,050,255
Year 10	$16,000,000	$6,000,000	$10,000,000	0.263	$2,629,530
Year 11	$16,000,000	$6,000,000	$10,000,000	0.227	$2,266,836
Year 12	$16,000,000	$6,000,000	$10,000,000	0.195	$1,954,169
Year 13	$16,000,000	$4,800,000	$11,200,000	0.168	$1,886,784
Year 14	$12,800,000	$3,600,000	$9,200,000	0.145	$1,336,085
Year 15	$9,600,000	$2,400,000	$7,200,000	0.125	$901,406
Totals	**$172,800,000**	**$70,438,000**	**$108,762,000**		

Net Present Value (NPV)	$32,433,539
Discounting Rate	16%
Internal Rate of Return (IRR)	110%

Values for Baseline Cashflow Chart

	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	
Yrly Net-Cash	($838,000)	($2,400,000)	$2,800,000	$4,800,000	$6,800,000	$10,000,000	$10,000,000	$10,000,000	
Cum-Cashflows	($838,000)	($3,238,000)	($438,000)	$4,362,000	$11,162,000	$21,162,000	$31,162,000	$41,162,000	
Baseline NPV	($838,000)	($2,906,966)	($826,109)	$2,249,047	$6,004,627	$10,765,757	$14,870,180	$18,408,475	

Gemcor Systems Corp.
Market Centered Multiproject Matrix Organization

Exhibit 8-8

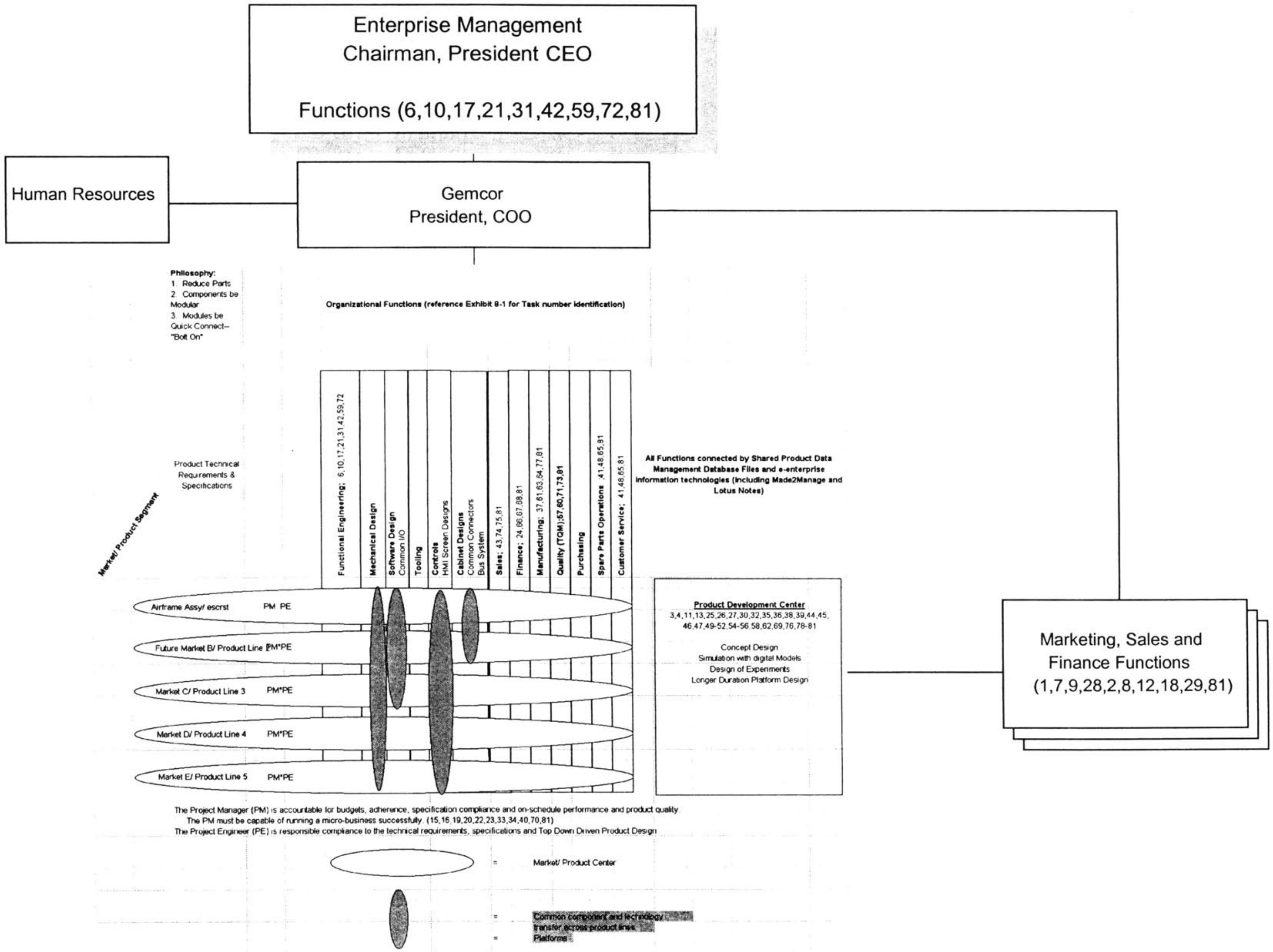


Exhibit 8-9: Framework of Comprehensive <u>Upstream</u> Considerations Before Beginning the Architecting Process (Function-Concept-Form): A Check List

- ❑ Must be process driven for consistency and comprehensiveness of upstream, downstream influences. The product concept and design process must be functionally in place and clear to everyone
- ❑ What system dynamics are occurring in the global economy and how does it affect the project/ product development in the short and long run
- ❑ Meet the corporate cost of capital hurdle rate requirement (usually at least 12% EBITDA)
  - ❑ Make sure there is enough available cash to support the project
- ❑ Be true to the vision, mission, values and guiding principles of the corporation
- ❑ Define the company's core competencies
- ❑ The human organizational processes must be in alignment
  - ❑ Vision, mission, values, guiding principles and goals
  - ❑ Incentives systems
  - ❑ Information technologies and communications structure
  - ❑ Empowerment
  - ❑ Trust
  - ❑ Stakeholders needs
  - ❑ Individual needs
  - ❑ The culture
  - ❑ Organization structure for ease of communication and cohesiveness, such as a market focused product market structure
- ❑ Have a technology strategy
  - ❑ Substitution threats
  - ❑ Intellectual property
- ❑ Be current in (understand) the legal and regulatory requirements
  - ❑ Is certification required?
  - ❑ Conform to required standards
- ❑ Have a product development (PD) process well defined and understood by the organization
    - ❑ Use an option pricing or other gated milestone go-no go staged process for PD
- ❑ Have a marketing strategy
  - ❑ Emphasize brand name
  - ❑ Know your current and potential complementary assets
- ❑ Use Quality Function Deployment techniques
  - ❑ Voice of the customer
    - ❑ Put customers on your integrated product team
    - ❑ Select supply chain members to participate
    - ❑ Ask and listen closely to what the customer perceives as his/her requirements and ask about how you will evaluate the success of your efforts
  - ❑ House of Quality
  - ❑ Determine customer and stakeholder requirements
  - ❑ Determine technical requirements
  - ❑ Determine conflicts in the technical and non-technical requirements
  - ❑ Know your price and derived cost constraint in order to meet the intended market segment economically successfully
  - ❑ Especially understand the human machine interface requirements
  - ❑ Meet the needed time-to-market to gain competitive advantage
- ❑ Benchmark (technologies, marketing, pricing, time-to-market, organizational structures, supply chain methods)
  - ❑ Competition
  - ❑ Companies which serve as models of excellence no matter what their industry

- Determine the goals of the project or product (use the SMART[88] principle)
  - Define the purpose of the product in non-fuzzy and quantifiable terms
  - The goals must be measurable
  - The goals must be reachable with stretch
  - Set the constraints for the project/ product
  - Product family and extensibility considerations
- Must develop a clear comprehensive intent specification prior to starting the architectural process
  - The system as a key component of the intent specification must go through a thorough decomposition. Decompose the problem (product development) into chunks, modules
    - Scope
      - Purpose expansion/ contraction
      - Behavioral definition/ analysis
      - Large scale alternative consideration
      - Customer satisfaction-builder feasibility
    - Aggregation
      - Functional aggregation (abstract)
      - Functional aggregation (to physical units)
      - Physical components to subsystems
      - Interface definition/ analysis
      - Assembly on timelines or behavioral chains
      - Collection into decoupled threads
    - Partitioning
      - Behavioral-functional decomposition
      - Physical decomposition (to lower level design)
      - Performance model construction
      - Interface definition/ analysis
      - Decomposition to cyclic processes
      - Decomposition into threads
    - Certification
      - Operational walkthroughs
      - Test and evaluation
      - Verification
      - Formal methods verification
      - Failure assessment
  - Keep the solutions simple
- Must consider the politics upstream
  - Internal
  - External
- Consider previous design history
  - Current customer/ user complaints (related to the VOC)
- Know your company's core competencies and strive to work with these and extend them where possible
- Consider the risks and benefits of the project
  - Relates to the zero defect policy
- Determine the operations strategy
  - Relates to the zero defect policy
  - Supply chain considerations
- Zero defect policy (as an upstream influencer)
  - FMEA
    - Probabilistic failure tree

[88] SMART is specify, measure, attainable, requires reach and is testable.

    - MTBF[89]
    - MTTR[90]
  - DFMA
    - Fault avoidance
    - Fault tolerance
      - Redundancy
      - Cross strapping
  - DOE
    - Understand the environment within which the product is expected to flawlessly and continuously work
  - Adherence to ISO 9001 with causal closed loop feedback for root cause analysis and corrective action
  - Safety/ safeware considerations
  - Be ready to design for testability
    - Downstream subelement tests
    - Final integration tests
  - Service requirements
- Is this project an incremental, radical or breakout product?
- What are your technical tradeoff possibilities?
- What is the current capacity available for the corporation? What resources will be required to make the project/ PD successful? Are the resources adequate or can they be made adequate to support the project/ PD?
  - Cash
  - Human resources
  - Factory
    - Space
    - Machine tools
  - Raw material
  - IT efficiency
  - Supply chain capability and capacity
- What is the financial history and current financial situation in the company?
- Who are the team candidates or team at the top for the project?
- Do we have the IT tools, such as LAN/WAN, CAD/CAE/CAM and solid modeling simulation for collaborative integrated product team design work?
- Have a well trained and diversified workforce organization
- Emphasize holistic thinking
  - Conduct training and seminars that help the workforce think outside their normal areas of interest. Expand their interests
- Make sure form follows function
- Keep in mind that perception is reality
- Define the boundaries of the project and since these boundaries are contrived, be sensitive to the interface of the boundary with the external environment
- At the start of the project, go through a checklist of upstream potential influencers to make sure they are all being considered as a part of the holistic view of architectural design
- Be prepared to adjust for changes in the upstream influencers
- If the project/ product is for global use, understand the cultural and legal regulatory implications
- Is the problem (the challenge) or product need properly stated or defined? How should it be stated?
  - Is this an incremental, architectural, modular or radical innovation?
- Use a supply chain network of experts to assist problem solving, stay current with present and future world and market events – scenario play the future

[89] Mean time between failure
[90] Mean time between recovery

All these above checklisted considerations play an important role in reducing ambiguity in preparing to commence the architectural concept design alternatives analysis and final concept decision.

Section 9

A Model of Sustaining Corporate Growth for Gemcor

The Enterprise in the Large
In addition to organizational structure, using system dynamics modeling techniques, the larger enterprise issue of sustaining corporate growth is of vital importance. The theme of the model described in this section is to study the dynamics of creating corporate growth for Gemcor with a positive EVA in perpetuity. So far, the answer to overcoming the forces limiting corporate growth and making companies vulnerable to ultimate merger, acquisition or failure have not been forth coming. The model incorporates product development as the means to fuel a diversification strategy with an increasing portfolio of products to create sustainability. The key feedback loops are the systems producing organization, the services and spares parts business, and of course the marketplace. Interwoven in the systems producing organization is the product line order fulfillment and the product development scheme to continuously replenish the company's portfolio of products and grow the enterprise.

The Assumptions of the Separate Business Units (SBU's) in the Model
The SBU's are two businesses within Gemcor. SBU1 is a producer of complex systems and SBU2 provides services and spare parts primarily for SBU1's products. The SBU1 and SBU2 are completely separate operating concerns with their own P & L responsibilities. They do not use the same personnel. SBU1's product portfolio can grow ad infinitum due to the goal to sustain growth and create positive economic value added (EVA). The SBU1 starts simply as a producer of custom systems in response to RFP wins. As it successfully fulfills orders, it grows per the positive loop diagram. SBU1 then develops an initial niche of excellence and core competence in a certain field and starts brand name building. It figures out how to design and develop a product family to satisfy this niche. Next, SBU1 penetrates other niches within a slightly wider but basically the same market segment using its core competence. Its evolutionary pattern of growth is the same, starting with winning custom proposals and discovering new product line possible developments to pursue in order to extend its set of products and product families offered. As SBU1 expands its presence in the current market segment ultimately to the point of saturation, it researches other market segments in which its core competence can be applied, and again following the pattern, enters and grows in the new segment. This evolutionary process can be continued into market segments forever. It is anticipated that each product/market exhibits a certain amount of cyclicality. The goal is to create an ever-growing portfolio of products and product families in different market segments. Within the product portfolio there will most probably be exhibited different phase shifts of cyclical oscillation, thus dampening the enterprise volume and profit resultant oscillation to a minimal amount. This minimal oscillation provides investors high predictability of the future earnings of the enterprise, lowers the investment risk, and makes the stock price highly attractive – maximizing the value of the firm.

In this model it is assumed that management will invest in new product developments and other proposals only if the marginal rate of return exceeds the marginal rate of cost. Obviating the need to include profit and loss variables. Not all products and proposals will be successful, but the gainers must exceed the losers or a downward spiral might precipitate.

SBU2 must grow at a rate sufficient to support SBU1's production, installations, and installed base of products in an efficient manner. SBU2 is vital to assure customer satisfaction of SBU1 products. SBU2 can apply its core competence to other product/markets beyond that produced by

SBU1 and will have a widely diverse set of market segments in which to sustain growth and generate positive EVA.

Development of the Model

The project started by investigating and modeling two loops of SBU1 and SBU2, which are synergistically joined at the center by the necessity for successful order fulfillment. Additionally the WOM model was connected to represent the market introduction of new products and their life expectancy.

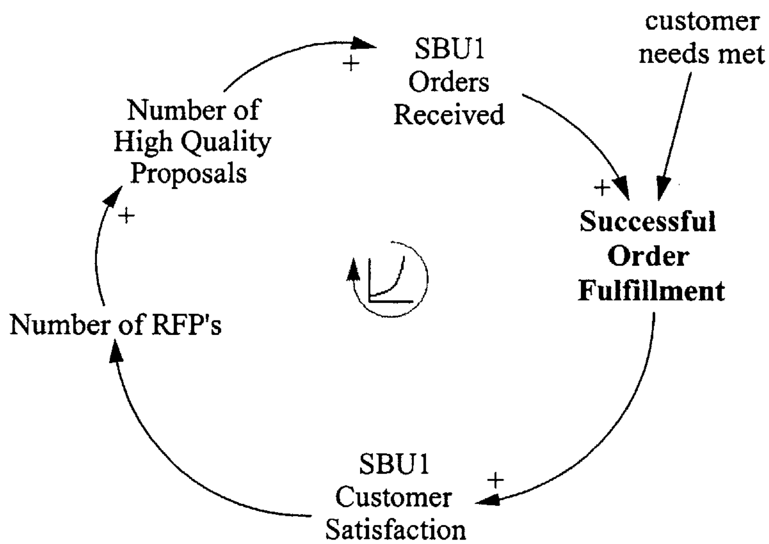


Figure 9.1 Order Growth of SBU1

The first loop depicted in Figure 9.1 starts with an order received by the separate business unit (SBU1) which requires order fulfillment leading to a level of customer satisfaction, and with higher customer satisfaction, greater requests for proposals (RFP's) are received and more orders are processed. This loop can be either spiraling upward or fall over time to zero.

SBU2 is a different business but has a similar pattern shown in Figure 9.2. Orders received must be successfully fulfilled with a sufficiently high customer satisfaction in order to maintain or preferably increase the number of RFP's to create a virtuous upward spiral; otherwise the business volume over time goes to zero.

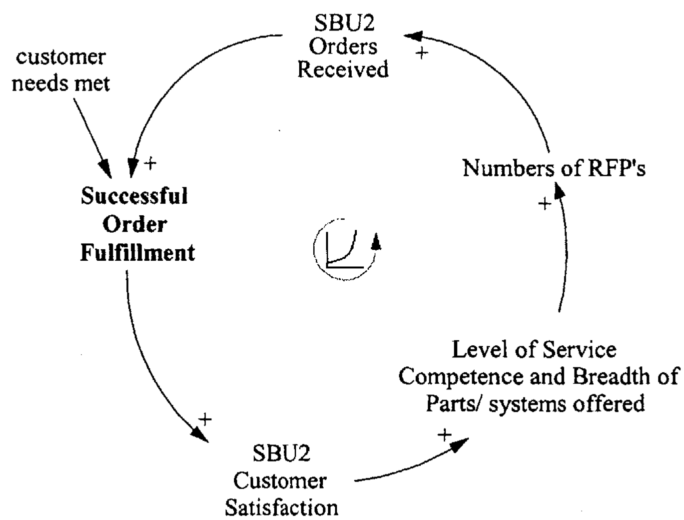


Figure 9.2 Order Growth of SBU2

SBU1 has two types of RFP's. Type I are those that are derived from the current portfolio of product families, and Type II are more unique requests, each one having the potential for the creation of a new product family. Depicted in Figure 9.3 is the inclusion of the Type II RFP's, which are the key to replenishing the portfolio of products in SBU1 and creating growth for the entire enterprise.

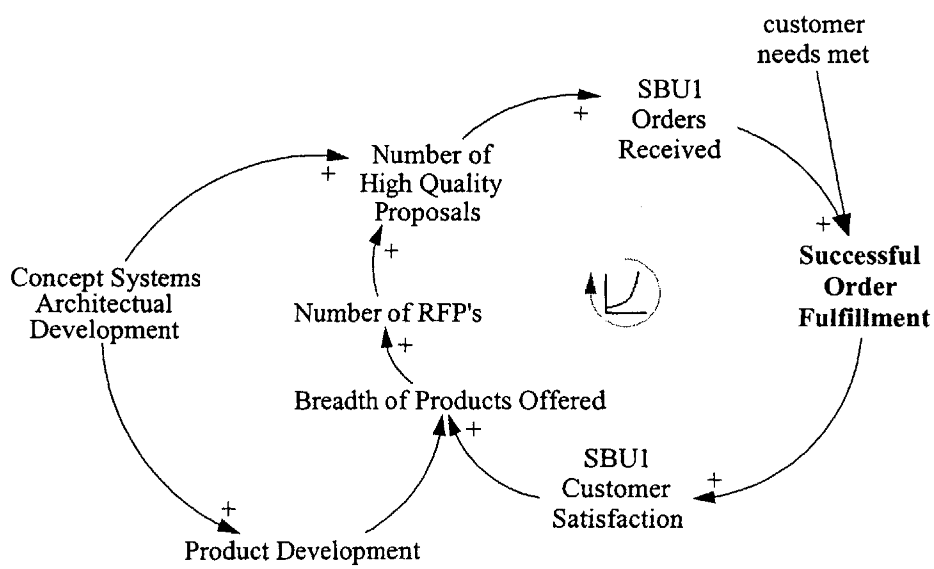


Figure 9.3 Product Development Loop Added to SBU1

The ratio of unique requests that have the possibility of becoming a new product development is approximately 1 out of 20. Similar conceptual systems architectural development practices must be applied regardless of whether the situation is a new product development or a unique design proposal. As the number of requests for proposals increases, likewise the potential for new products increases if there is successful order fulfillment and a sufficiently high level of customer satisfaction.

The causal loop diagram (Figure 9.4) depicts the two separate business units' that are strategically and synergistically attached and exist within a larger enterprise organization. One company sells products (SBU1) and the other company sells services, does equipment reconditioning, and sells and produces spare parts (SBU2). Neither company can exist without the other since they currently share the same market segment. As SBU1 creates the products, the other SBU2 tests the products before shipment, installs the machinery, and lives with the customer during production startup to achieve a successful handoff of complex machinery to its customers. Afterwards SBU2 supplies spare parts and provides further support services. Together they fit the archetype of "success to the successful," in other words, success breeds success. SBU1 produces complex, large-scale automation systems for various markets and especially aerospace. Its parent has investigated the acquisition market for growth and has decided instead to create growth, using its custom design and project oriented core competencies by developing product lines in each market segment within the industry of assembly automation. The purpose of this modeling effort is to discover the important variables for increasing economic value added for the companies, to increase the product development creation rate of product lines, and to increase the order win rate. The order win rate refers to the number of orders received by the SBUs compared to the total number of bids as a percentage of requests. The goal is to win > 90 percent of all bids. It is the intention that these two SBUs in this model and other SBUs in the organizational system grow at as fast a rate as possible while exceeding the required cost of capital, creating a positive EVA composed of the portfolio of companies and their respective portfolio of product lines.

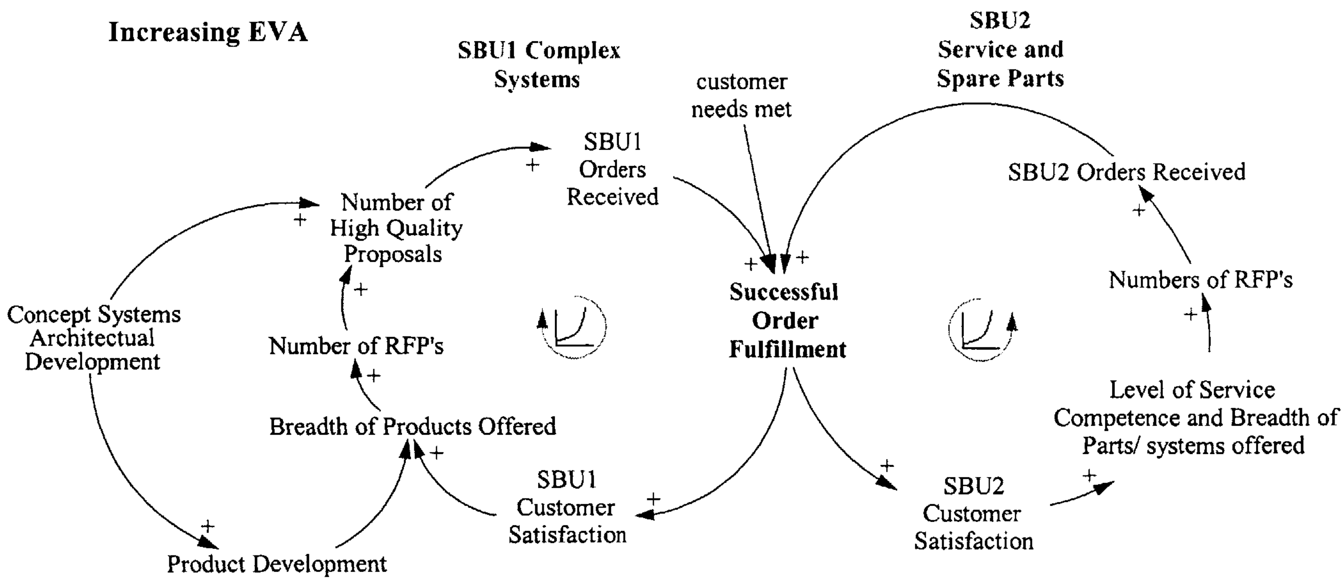


Figure 9.4 SBU1 and SBU2 Synergism via Successful Order Fulfillment

"Successful order fulfillment" and "customer satisfaction" are important factors in driving successful virtuous upward spirals of requested proposals, unit sales, and the breadth of products offered by product development. Order fulfillment to be successful must satisfy the customers' and company stakeholders' requirements to create this virtuous spiral. Likewise, unsuccessful order fulfillment causes a downward spiral which cannot go below zero. Orders must be successfully landed, with customers pleased at their decision placing orders with us. The SBUs must perform in compliance to the technical and contractual requirements as well as meet or perform better than the budgets and schedules of the orders. This process must be accomplished in a competitive market context as modeled in Figure 9.5.

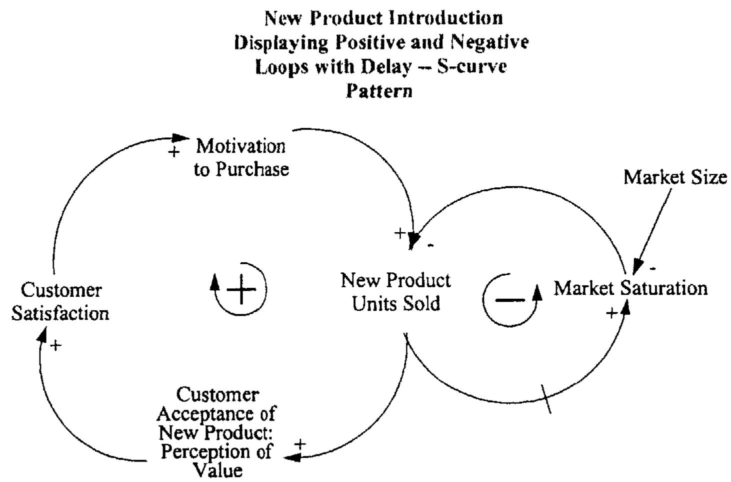


Figure 9.5 S-curve Pattern of New Product Introduction to the Marketplace

The market model demonstrates the S-curve pattern of a product's life-cycle. As a new product enters the market, it is typically accepted slowly at first and is thereafter rapidly accepted until it reaches a point of maturity and then eventual decline caused by new product/technology substitutions. The S-curve pattern is caused by a positive reinforcing growth and negative balancing loop interaction. The positive reinforcing loop of a product is the customer acceptance based on perceived value derived from the product, the satisfaction level followed by the motivation to purchase which leads to more units sold. The counter-opposing loop is caused by market saturation. A more sophisticated product/market behavior representation is shown in Figure 9.6. Word-of-mouth (WOM) spreads the perceived value of a product to the marketplace. There is a stock of prospective customers and a stock of those customers who have actually purchased the product. Those product user customers come in contact with the prospective customer base, which increases or decreases the sales of the product based on the word-of-mouth. The product growth if it is successful follows the S-curve pattern until market saturation occurs.

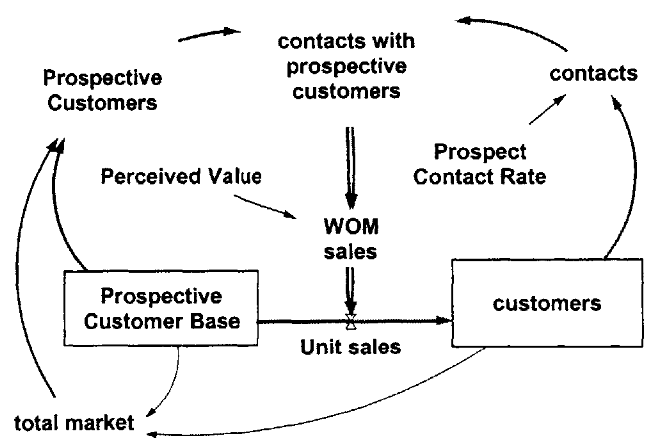


Figure 9.6 WOM Market Penetration of a Product

Successful order fulfillment in each company drives customer satisfaction. Customers are attracted by the products offered and the perceived value of these products. In addition, customers are attracted by brand name and word-of-mouth reputation. A significant factor in building reputation is the successful order fulfillment and service/spares support to help assure that customers are successful in the utilization of the products they have procured. When a customer chooses to purchase a product, they are putting their trust in the supplier to satisfy their wants.

It is the intent to develop new product lines for different market segments, all of which match the core competencies of a single SBU or the collection of SBUs, as quickly as possible. A purpose of this systems dynamics modeling effort is to create a template or methodology for enhancing the quantity and quality of new product lines. It is the desire in constructing and simulating this model to show management the importance of the SBUs, products and services, working very closely together to generate requests for proposals (RFP) at a high rate, increasing the rate of new product launches and corporate growth. The expectation prior to running the simulation is that the virtuous spiral loops will rise exponentially without limit. Although no oscillations are expected in a perfectly running system, it is anticipated because of lags or delays in different steps in the system that oscillatory behavior will occur. It is anticipated that as the portfolio of SBUs increases and as the portfolio of their product lines increases, the oscillations will dampen. This behavior is analogous to the diversified stock portfolio finance theory, that the more diversified a stock portfolio becomes, the less volatility is exhibited in its total value. Delays have been introduced in the time to go from high quality proposals to actual unit sales, and separately in the time it takes to generate new products from product development efforts.

The depiction of the causal feedback loops diagram is an excellent tool in team management meetings for developing corporate strategy. Much of the strategy development occurs by the process of building the model itself. Figure 9.7 represents the first attempt to connect all of the earlier loops into one network.

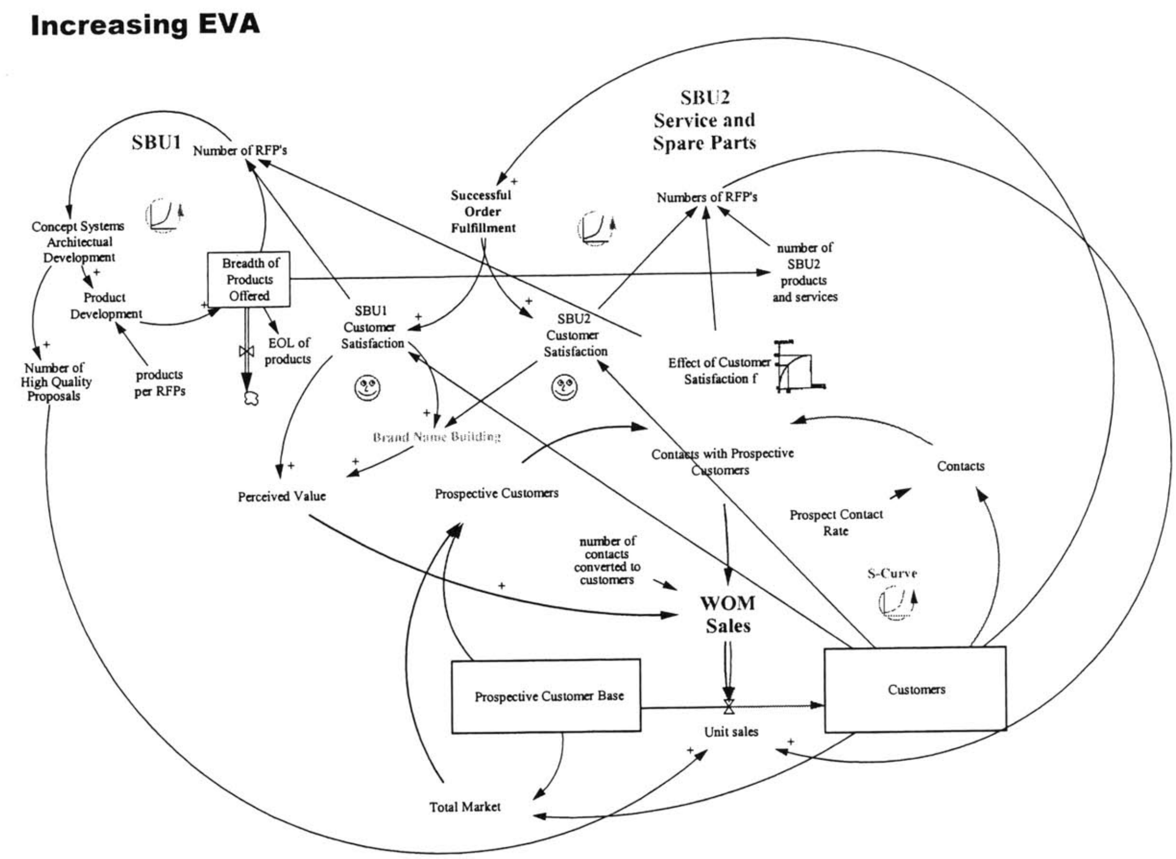


Figure 9.7 Initial Interconnection of the Primary Loops

While the model shown in Figure 9.7 is comprehensive, it is also very difficult to analyze and debug. A simpler version of the entire network with a stock and flow model captures 3 main stocks: SBU 1 available products, SBU2 available services, and customers. (See Figure 9.8)

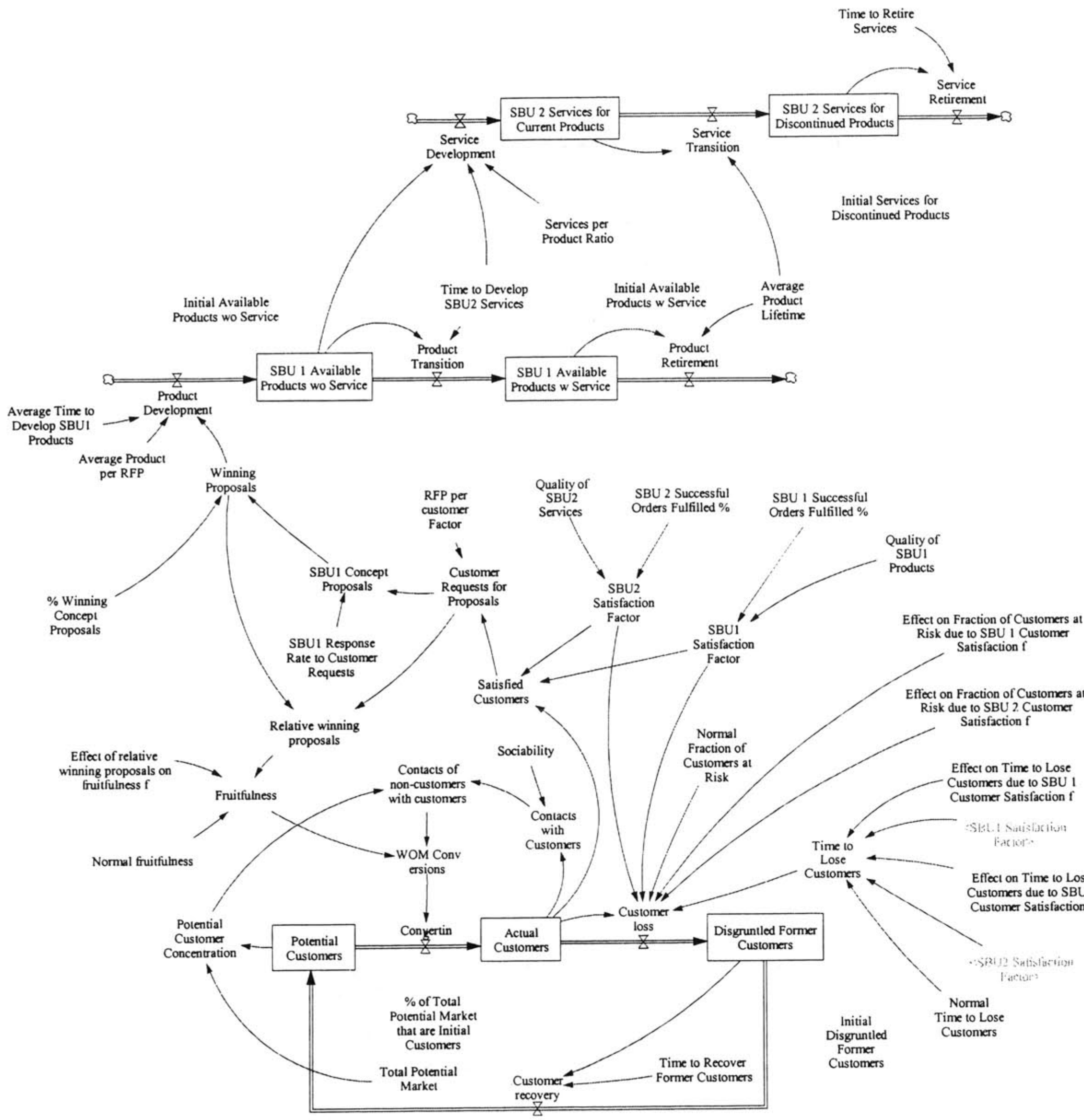


Figure 9.8 A More Simplified Model[91]

[91] The model described was introduced by the author in the form shown in Figure 9.7 to his SDM colleagues Messrs. Christopher Burns and Luis Rabelo who worked with him to create the more simplified model. The author is very appreciative for their collaborative efforts. It is planned that a joint technical paper will be submitted on this subject to a journal for publication and presentation in the near future.

Model-Derived Policy Development

Inflection Points[92]

The equilibrium quantities in the model shown in Figure 9.8 hereinafter referred to as 'the model' are the inflection points where variation would cause a spiral. Any oscillations in the model are quickly overcome by the strength of the two main positive reinforcing loops. Each variable in the model must have a policy or set of policies aimed at preventing precipitous downward spirals. This discussion on policies will cover the main variables. The policies are designed to address these inflection points.

Critical Balances and Rates of Change

Rate imbalances are sources of limits to growth or decline. An interesting question is whether the enterprise management can rely on the invisible hand to keep the balance of growth between the two SBUs or does it have to closely monitor the balance and exert controls to assure the balance. For instance, a situation can occur where there are inadequate service personnel or infrastructure to assure SBU1's products are properly serviced; as a consequence SBU1 might grow faster than SBU2 can adjust to close the gap between the symbiotic rates of growth. An imbalance is dangerous since the satisfaction level will be reduced, and at some critical point the vicious spiral downward will start. The danger of downward spiral generates the need to maintain metrics for enterprise and SBU management as well as worker visibility to keep key controllable variables on the right track. These key balances are cash availability, SBU1and SBU2 growth rates, customer satisfaction, infrastructure growth rate, risk aversion, order win rate, and diversified portfolio theory adherence.

Cash

As is typical in growth scenarios, cash is required to keep up with the pace of growth. The rate of positive net cash flow generation must equal or exceed the rate of cash needed for new product development and other organizational needs. If cash becomes the constraint, then growth will be slowed. Management can choose to obtain more cash by stock offering, but this has a dilutionary effect on current shareholders and can be used only if the result is that the discounted future stream of earnings per share will be higher. Another option is to use debt. The cost of debt has two issues, the interest rate and the risk of not having enough cash later to pay the interest and principle. These issues make debt a poor choice to fund corporate growth for a company, which will need increasing amounts of cash in the future to fund the growth. A lack of cash crisis can significantly limit growth and potentially start a downward spiral.

Cash availability is so important that a product development can occur only after the following criteria are satisfied:

Criteria for Product Design and Development (PDD)

1. Provides a positive net cash flow and economic value added with a 25% cost of capital
2. Takes less than twelve months to design, develop and get on the market
3. Requires less than $1 million to design, develop and introduce to the market
4. Fits the core competencies of the corporation
5. Provides a sustainable (2 year) competitive advantage in the form of better, faster and cheaper than other customer alternatives
6. Can reach an investment breakeven point within 6 months after market introduction

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[92] Only the Paranoid Survive, Andrew Grove, 1996, Bantam Doubleday Dell, audio version.

7. Must provide $1 million positive net cash flow in the first 12 months
8. Product has a life cycle market value of greater than $50 million and 250 units in the total potential market
9. Must emphasize simplicity of solution
10. Must be patentable (must not infringe on any patents)
11. Must be robust; meets form, fit and function and rapid market acceptance
12. Stage gate project management and option pricing, product portfolio management techniques are to be applied[93]

Cash might be a variable to add to the evolving model, which would be a stock with a rate of inflow as a result of to products sold at a net cash gain and an outflow to pay for new product development costs, total direct costs of the operation, and total fixed costs. The policy is to maintain the rate of inflow > the rate of outflow of cash. At this point in time, we have concluded that this policy and measurable is so basic that its inclusion in the model adds no value and increases model complexity unnecessarily.

Growth Rate of SBU1 vis-à-vis SBU2 (Service must keep up with products requirements alignment)

List of important variables to be addressed:
Personnel assignment
Personnel requirement
Personnel retention
Personnel training

The rate of SBU1 growth must be equal to or slightly less than SBU2 as measured by products with service compared to products without service (SBU 1 Available Products w/ Service > SBU1 Available Products w/o Service). Because of the time to develop SBU2 services and product transition rate, SBU2 must keep metrics indicating the rate of product development, with time allowed to assure services are available ideally just before the product/market requires the services. This is because SBU1 must have services to test and install their products, and SBU2 must at the same time maintain the installed base of systems to keep order fulfillment on time and the customer satisfaction level high.

Not all possible variables can be or should be included in a model; otherwise, in the extreme, the entire universe would be included. Instead, the essential variables to the study at hand need to be included, which is of course judgmental. Below are two models which can separately serve as references for understanding the subset balances which must be attained in any successful firm. Figure 9.9 is for workforce, inventory, demand fulfillment, and productivity. The model in Figure 9.10 must be used for understanding the dynamics and time required to hire, train, and maintain a competent skilled workforce, especially appropriate for SBU2. These types of models could be added to the existing model to address these issues.

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[93] "Scientific Management at Merck: An Interview with CFO Judy Lewent," N. Nichols, *Harvard Business Review*, January-February, 1994, Pp. 89-99.

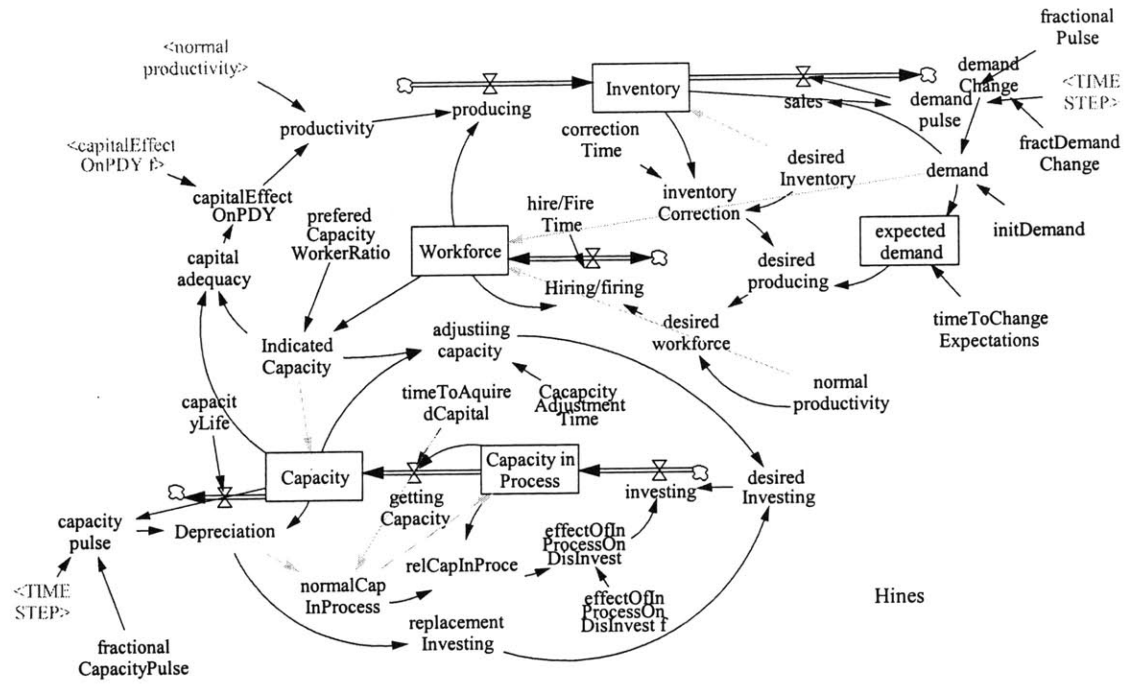

Figure 9.9 The Dynamics of the Workforce, Capacity, Inventory and Demand in the Enterprise System

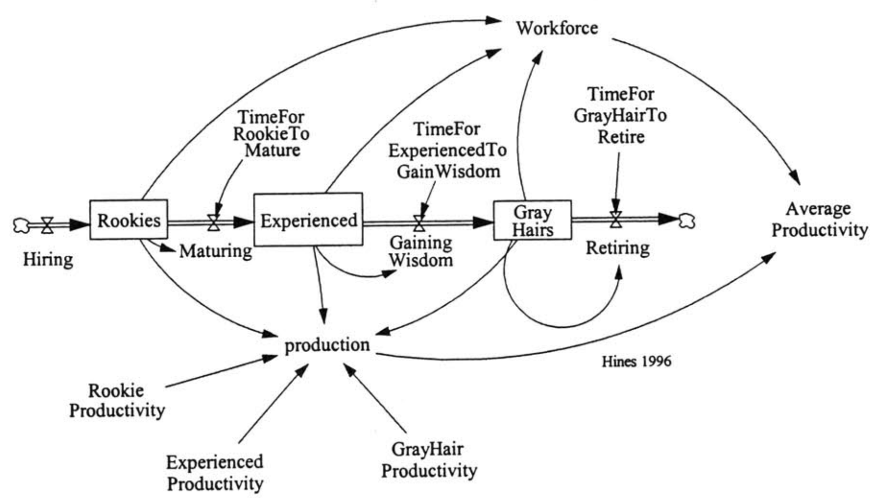

Figure 9.10 The Dynamics of Building a Skilled Workforce (i.e., SBU2 Service Workforce)

Customer Satisfaction

TTM

The faster product development and production bring products to market in a high quality manner, the better.

System Uptime and Utilization

Operational Effectiveness of Equipment is a current terminology being used to emphasize uptime utilization of equipment. The greater the uptime the better, especially in bottleneck zones which determine the rate of throughput.

Order Fulfillment

There is clear evidence in the model that the time to develop products has a dramatic effect on the business. A policy must be targeted to reduce time-to-market. The time also has an almost 1:1 correlation with cost although not modeled here. So, cost will likewise be reduced if the time-to-market is quicker. The Average Product per RFP is highly elastic with the SBU stocks as expected -- the greater the ability to produce products from RFPs the better. The RFP per Customer Factor is very important to the behavior of the SBU stocks. Naturally, companies want to increase the number of proposals submitted to the customers and increase the winning percentage to create a thriving enterprise. The "SBU 2 Successful Orders Fulfilled %" is highly related to quality. Frankly, lateness on orders cannot be tolerated due to the onerous effects on increasing costs (not modeled) and degradation in the business. For project management, if delays arise in a schedule, they must be diligently time recovered back to plan, using techniques such as explained by Goldratt.[94]

Customer satisfaction is an important dimension to take into consideration for the success of the modern enterprise. It is essential to consolidate, analyze, and establish policies to guarantee customer satisfaction. This policy making process occurs throughout the marketing, sales, and service stages.

The model demonstrates that increasing customer satisfaction enables the company to identify, contact, and obtain new customers by targeting promising markets. The WOM factor will accomplish the conversion of suspects to prospective customers. Also, the behavior of the model indicates that increasing the winning proposal rate increases customer satisfaction, which in turn enhances the conversion rate. This finding emphasizes the importance of winning market share. However, even if the winning rate of orders is initially low, if the order fulfillment rate increases customer satisfaction, it will in itself have an ameliorative affect on winning future proposals then and increasing the number of actual customers.

Sociability

Improved sociability will increase customer satisfaction, which can be accomplished by direct contacts, newsletters, advertising, newsgroups, and "chat" rooms related to the products and services. If sociability is low, then even high order fulfillment will not increase the satisfaction level. The model indicates that customer satisfaction should be approximately 95% to sustain upward virtuous spiral. Even a 90% rate will not significantly raise the positive loops.

Infrastructure

Another potential source of imbalance is the rate of infrastructural development to assure successful order fulfillment. Infrastructure development can be quite complex. Talent can be difficult to recruit and retain in the competitive market. Training takes time and is expensive. Support process systems and tools take time to design, debug, train and become accepted in use. Infrastructure is also a process to control the organization and prevent downward spirals. Providing the process improvements for the organizational structure to support and encourage further growth is a difficult management challenge. In addition, synchronization of the supply chain infrastructure to the needs

[94] Critical Chain, E. Goldratt, North River Press, 1997.

of the organization in the form of timing, quantity, quality, logistics, and price is vital for successful order fulfillment and customer satisfaction.

Risk and Change Aversion
Growth limitation and potential decline is well described by Christiansen[95], which is the failure of the organization to adjust to and accept change both from the outside and within the organization. This reluctance to leave the comfort zone of the organization and put on blinders to possible technological substitution is a serious problem frustrating the sustainability of the firm. The model deals with this problem by emphasizing product development, which is change. However, will the products be merely incremental or will they be truly breakthrough? A possible policy could be to engage in a product development which has at least a 50% cost and TTM improvement, as well as features superior by a 50% margin over the competition. This could be called the 50% rule. If the new product development candidate is 50% lower cost (at least to build; one could sell at a higher market price if possible), faster TTM, and better, then the project will be undertaken. Products must also be diversified into different market segments. The organizational structure must foster this product/market approach.

Order Win Rate
The model is very sensitive to winning percentage. A slight change sends it spiraling upward or downward very quickly since most of the loops are positive. Customers in reality can be very sensitive and not place orders if they are dissatisfied, or for a host of other reasons, this sensitivity should not be ignored. Customers can be either very cold and unforgiving, or they can be very tolerant depending a great deal on how they are treated, and they must be responded to accordingly.

Other policy steps can be listed which can dampen a downward spiral tendency while the business is striving to improve the customer satisfaction level. For example, active discussions with existing customers to identify ways to improve customer satisfaction can be accomplished by assigning executives to specific customers and requiring a few personal visits each year. Competitive analysis to learn why the SBU did not win a certain RFP is also another option to improve the order win rate in the future. Finally, actively and thoroughly communicating to everyone in the firm the status of key variables, like customer satisfaction levels, order win rate, average number of new products per RFP, etc., will help energize the work force and enlist everyone in developing ideas and action plans for future improvement efforts. That brand naming can have a dampening affect on the downward spiral sensitivity is a hypothesis that requires further development in terms of the model.

Adherence to Diversified Portfolio Theory
SBU1 must incentivize to not only pursue growth from in the current product families but create new product families in new market segments as well. Typical behavior is that people like to stay in their zone of comfort. Even in a product development area, people tend to improve on the known past in the form of incrementalism rather than take the risks of going into new breakthrough territory. Usually the incentive systems in corporations inhibit or penalize those who take a daring risk and lose. The sanctions imposed serve witness to others in the organization to not take these risks. However, the model requires that SBU1 diversifies into new market segments as well as grows new products within existing market segments. A risk and reward system must be modeled which demonstrates the desired behavior of multi market segment penetration with new product families. Top management must emphatically lead the way in funding system architectural teams in

[95] The Innovator's Dilemma, Clayton M. Christensen, Harvard Business School Press, June 1997.

the different market segments. It seems that the biggest gamble lies in accurately understanding the wants of the perceived new market segment. An outsider to a market has the disadvantage of not intimately knowing the customer drivers without a thorough market research investigation. On the other hand, the outsider might be able to bring into the market space fresh new ideas unencumbered by past paradigms. A policy for entering into the new market space must account for the added risk, therefore requiring again that the new product line be at least 50% lower cost to build, 50% better in features, and 50% faster in time-to-market, with an equal or preferably enhanced quality compared to existing competition.

EVA Measurement and Incentive System

Rather than profitability, EVA has been chosen as the financial theoretical basis for measurement of the firm's successful contribution to society. The contribution margin policy must be able to sustain a positive EVA along with a positive revenue growth.

Truth

A model is an abstraction that attempts to depict reality. Science uses empirical tests to verify laws and theories, yet organizations are generally too complex and interactive with externalities, making it very difficult to set up general and repeatable experiments to conduct tests of the truth in a constantly changing environment. Is this model telling the truth, how do we verify its veracity?
This model is a theory which seems to fit published case study behavior of organizations in the experience of the author. The policies will serve to guide Gemcor's organizational behavior, and results will be tested against the model for further alignment of the model to reality.

Conclusions Derived from the Model

Many processes, and attentiveness to these processes, underlie the success or failure of the interrelationship of SBU1 and SBU2. The model described herein cannot cover every aspect of the operation of the enterprise but nevertheless emphatically points out the sensitivity of successful order fulfillment in products provided and necessary services support to the customer. Any deviation from the equilibrium points affects customer satisfaction and the positive reinforcing loops. On the one hand, the model demonstrates in an alarming manner the precipitous downward spiral which may be exhibited too often in the lives of enterprises. On the other hand, the model shows the virtuous spiral of growth that is indefinitely sustainable if the inflection points are not crossed. Borrowing from sports, the term momentum can be used to describe this upward spiral. The model expresses the optimism a company or enterprise of SBUs can possess by managing above these inflection point thresholds, pointing the way toward continued corporate sustainability and toward enrichment of its shareholders, customers served, and other stakeholders.

The model demonstrates the constancy of and virtual need for change in a sustaining organization. Much has been written about the accelerating rate of change related to technological change, but the model shows that change is inherent in a sustaining growth corporation regardless of technological change. Successful product development is the catalyst of change, and order fulfillment with high customer satisfaction is the necessary sustainer to the virtuous spiral.

The factors leading to the development of a new product line and the design of an organizational structure to support this first of expected many product lines have been described. This is the origin, but much work needs to be done. The initial results are positive, providing the confidence to lead into the future by the strategy developed herein. Our goal is to sustain corporate growth, while providing economic value added, increasing market segments served, increasing new product line development rates, and increasing the order win rate.

Section 10

Summary and Conclusions

In the pursuit of the development of a new product line and the design of the organizational structure to support the first of the expected creation of many product families, it has been the intent to apply the core competencies of Gemcor towards sustaining corporate growth with a positive economic value added. Gemcor started in 1936 as a design and welding company, later finding its niche in catering to the airframe production market during World War II. By the time of the 747 launch, Gemcor had developed a reputation of being the premier, commercial airframe, automatic fastening systems producer in the world. At that time Gemcor's interference fit slug fastener and automatic installation design drastically simplified commercial and military transport wing production, with a lighter wing structure, fuel tight bladderless wing tanks, higher fatigue life, and automation of the assembly. Furthermore, the slug fastener is relatively inexpensive compared to alternatives for wing assembly.

However, the position as a sole supplier held by any company in the marketplace is rarely tolerated by customers for long. Competitors are either created or otherwise attracted to the market by customers. The challenges described herein have been based on the search for a sustainable, product driven, competitive advantage within the current market niche of the company using a methodical process through which product development, excellence in order fulfillment, and an outstanding service and spare parts organization can lead to diversification in the global industry of assembly automation.

The strategical development in this study began with the writing of the corporate mission/vision statement, setting of the corporate financial objectives, and self-discovery of Gemcor's current core competencies, which together with its complementary assets, could be applied towards product development and diversification initiatives. The study then considered the technological factors affecting the strategy for Gemcor. Within the relevant boundaries of the Gemcor operation, all perceived technological influencers were examined and described, especially with regard to their possible effect on the future state of Gemcor. The umbrella under which Gemcor's core technology interests exist is the broad category of joining automation technology as it relates to automated assembly equipment. Joining technology can be divided into mechanical fastening, heat fusion, and chemical bonding. The technological trajectories appear to indicate that Gemcor's Escrst™ new product line is well positioned to support the commercial aircraft assembly requirements through the year 2010 at least. It was concluded that the need for automatic fastening would not be substituted immediately by other technologies.

The world and industry trends and demographics also were analyzed with respect to their effect on Gemcor. There is excitement in the industry caused by the imminent launch of the very large transport aircraft by Airbus, A3XX, and potential counter reaction launches of the 747 and 777 X's by Boeing. In addition, there is the immediate potential launch of the military cargo aircraft in Europe called the A400. Rarely in the past cycles of the commercial aircraft and military transport industry have there been four simultaneous launches. These launches will be in addition to an already in process upswing in the cycle for new aircraft, which is driven by the growth rates of the air cargo and passenger airplane markets. The greater use of e-commerce, rising world GDP, and stability of the world economically and politically relative to the past, led by the strength of the United States economic growth, has increased the air cargo and passenger traffic demand. The fairly recent rise in oil prices is deemed to be essentially the attainment of a proper equilibrium of supply and demand. Even the anticipation is for stable oil and jet fuel prices for the long-term. The economies of the countries with the highest air traffic markets were examined for their robustness as anticipated over the next 10 and 20 years and their possible effect on cargo and passenger growth rate forecasts. Within the commercial aircraft industry Airbus and Boeing were analyzed and their strategies mapped specifically as they relate to Gemcor. The exercise of understanding the competitive environment of the commercial aircraft industry is an important part of the alignment process of any supplier to better serve its key customers, such as Gemcor with the Airbus and Boeing groups or other targeted markets such as the regional jet producers now dominated by Bombardier, in addition to the more emerging markets, Russia and China. A three year forecast of the potential automatic fastening systems market was derived from this analysis.

In addition to highlighting specifically targeted customers by this exercise, the strategy for attaining competitive advantage to "win the market" was formulated. There will be a significant ramp up of demand and requirements for production capacity over the next three years. Whichever supplier of automatic fastening systems can deliver in a timely manner with quality systems over this period will be the winner of the ride up the S-curve of the market. Each of Gemcor's competitors was analyzed within the commercial airplane market niche of automatic fastening systems. Different competitive strategies were formulated and discussed for making Gemcor the premier supplier in this niche. The ammunition for winning this market competition consists of the products each competitor possesses and can develop in the near-term, supply chain complementary assets, and strategic partnerships.

The automatic fastening system was described historically, from inception to the current state of the art. The functional derivation of the electric servo control roller screw technology application and automatic fastening systems was developed. This first product family development pursuit of Gemcor is extremely important to fulfill the corporate strategy, not just for today's competitive advantage, but to set a model upon which product development replication can occur. Upstream and downstream influences and goals decomposition were conducted. The customer supply chain and system architectural needs hierarchy were determined. The coupling of function and design was analyzed, and different alternative architectures were developed based on these functional groupings. Core technology tests were performed. Once selected for the new product line, the baseline technology was patented. Staged technical testing was conducted with customer involvement in design and with total market preliminary demonstrations to gain positive feedback and criticisms to help create the best system on the market. In 1999 the new Escrst™ product line was introduced to the market. As is typical with a new paradigm, this technology is following an S-curve of acceptance into the marketplace, first led by the specialty users and their positive word-of-mouth, which has attracted other customers to the new better-faster-cheaper product family of automatic fastening systems for commercial aerostructures. The family is based on modularity for flexibility and extensibility, quicker time-to-market, lower costs, and the ability to incrementally improve robustness over time.

Since the 1980's, the organization at Gemcor has followed a weak matrix structure. It has begged overhauling in order to operate under a heavy program management, product development driven organization dedicated to meeting corporate objectives and market segment wants, and then leveraging off the common pool of functionally grouped specializations. Using the design matrix structure, organizational best practices (especially from the Toyota Corporation), and the powerful use of project teams, a new market centered, multiproject, matrix organization has been created to meet the needs for the current product/market niche and anticipated market segment diversification with future product families in the potential market segments of the automatic assembly industry previously described.

The final section of this study used a system dynamics model to better virtually understand how an enterprise in the large, Gemcor Systems Corp., with its two business units, an automatic fastening system producer and a services and spare parts provider, can interact to create sustaining corporate growth with a positive EVA in perpetuity. The model shows theoretically how this can be done. The key parameters for creating the virtuous spiral of exponential growth of the total enterprise are high sociability with customers and supply chain members and excellence in order fulfillment. The two factors combine to create positive customer satisfaction, leading to the desire by these customers to purchase more of the company's products and to spread the word-of-mouth, thereby generating more customers. By these purchases the required cash is generated for further product developments to perpetuate increased growth of the SBU's and the enterprise. The model also helps visualize the need for keeping the growth rate of services and spare parts, SBU2, equal to or greater than that of the system's producer, SBU1. It shows the need for positive cash generation to fund the product development and growth as well as balancing the infrastructural rate of development to assure successful order fulfillment. The danger of risk and change aversion was studied as well. It is critical to the organizational structure to foster new products/market diversified growth by incentivizing the desired behavior of taking calculated risks into new market segments using stage gate controls. Further, the model demonstrates the constancy of change inherent in a vibrant sustaining growth corporation. Therefore, the goal should be to break down the inertia for remaining within the company's own comfort zone, instead continuously identifying and fulfilling new or different market segments with truly valuable product families.

This case study has employed a holistic systems approach to analyzing, reorganizing, and redirecting a company operating on historical and traditional methods. The purpose for the extensive investigation into current and potential market wants, the customer status, competition, world economic effects, and technological trends in automatic fastening of aircraft was to help orient Gemcor for its greatest opportunities for success in its market of the future, which rapid technological change is delivering here already. This paper serves then as the documentation of these research and analysis effects and the steps by which the results led to a re-engineering of the company's organizational structure and product development process.

Section 11

A Normative Approach to System Architecture Concept Development in Product Development

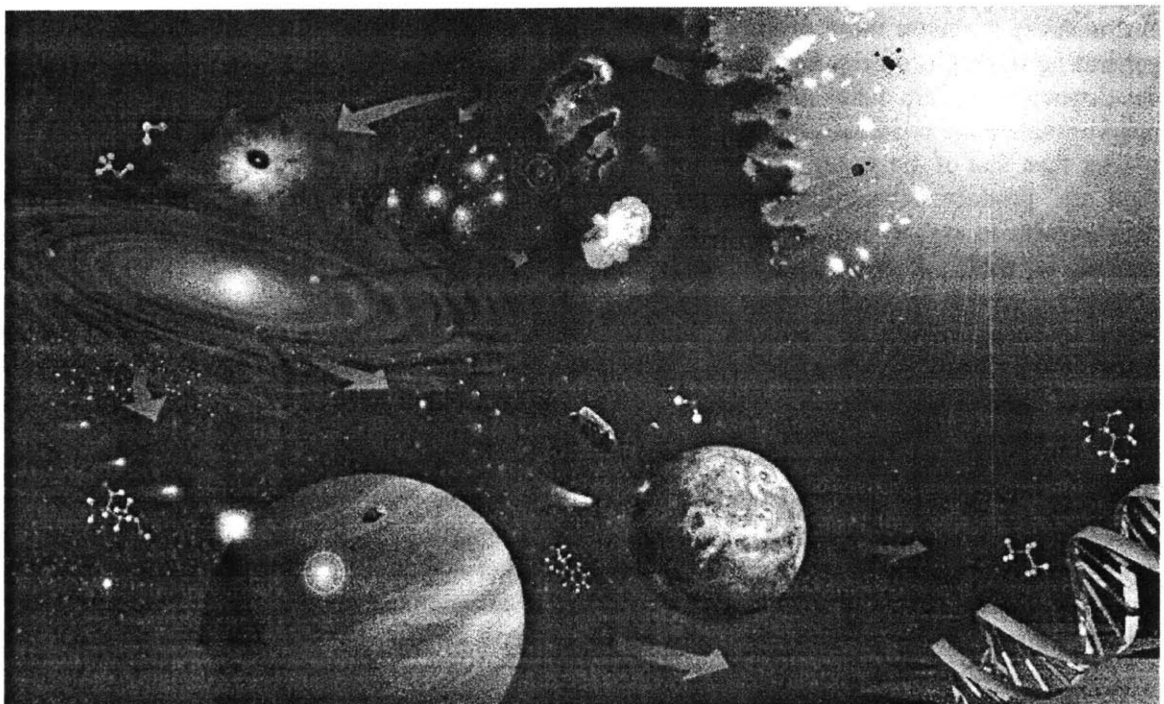

Figure 11.1 The Creative Process[96]

The preceding case study is a current application of best practices in system architecture and product development. However, the author desired to think ahead as to the future methodology of system architecture. It is the intent of this section to converge seemingly different fundamental subjects in physics, genetics, chaotic behavior, evolutionary theory and computation into a normative approach to concept, system architecture development and selection. In product development there should be a natural essential order to be discovered. How can we more programmatically develop products that are flexible and adaptive to their environment? How can we develop products that are simple yet contain the necessary complexity to meet the form and function requirements? How can we programmatically develop form and function to meet the needs and wants of individuals and entire markets? The method to be described is a 10-20 year look in the future of how system architecting might be accomplished to better serve the wants of the customer.

The programming method of the genetic code, the laws of physics, and the selective adaptive process, in combination, are applicable to the determination of the best form-function concept. Genetics is both deterministic to a large extent and a statistical process of determining form-function (F-F), while physics is an externality with which the F-F must adapt. (See parameter diagram Figure 11.2) Many rapid repetitions of creating F-F's could bring a close approximation to the ultimate best design, similar to the way Monte Carlo simulation by thousands of repetitions finds a mean and distribution which ultimately has no statistical variance between further

[96] Courtesy of NASA/JPL/Caltech

iterations. In product design concepting another externality with which the F-F must adapt is the human psychological aspect. Other externalities are to be quantified in the intent specification.[97] The survival of a product, and of the firm which produces the product, depends on the product's market success with customers who have individual as well as common group needs and wants to be satisfied. The purpose of the enterprise is to make money, which it does in part by satisfying customer wants by means of selling products. The need-want satisfaction is a basic and critically important input parameter which must be determined by the product developer. The customers have an insatiable need-want desire, are attracted by product choices constantly, and are constrained by possessing a limited amount of cash to expend on the products. Therefore, the customer must make a decision. Numerous factors affect customers' decision making: group politics, want satisfaction, emotion, culture, timing, competing wants to satisfy, product availability, technological change, and rapidity of change. The marketplace and product development can be likened to the adaptive survival process of species. The term adaptive refers to the degree by which an organism changes with respect to changes in the environment in order to survive. The marketplace is to product success as the environment is to a species' survival. I propose that a product, product family, and its platforms be equated to a living organism. The evolution of inanimate to animate objects is a natural process. Therefore, it may be quite rational to superimpose the inanimate onto the animate, particularly in product development and product life cycle management, in order to understand F-F and concept choosing from the deep study of physics, genetics, evolution, chaos and computation.

Not all F-F possibilities are consistently used to create the living being. By the chaotic, least action process of attractors, chance and the reinforcing of certain F-F's by species' breeding choice over long periods of time cause enough iterations to be performed to modify the F-F. Since parameters change, some by choice and some not, the F-F is constantly itself changing – the evolutionary process. In product design the lifecycle of the product depends on the amount of change in the parameters over time. (See Figure 11.2) The fruit fly clock speed analogy is appropriate.[98] The faster the parameters change, then the shorter the product life cycle and the faster, more often that products must be created, transformed or evolved from earlier designs.

However, at any moment in time the parameters are unchanging. A genetic self-organizing process, along with chaos, physics, and a Monte Carlo iterative evolutionary process, could be used to approximate or statistically determine the best F-F at that instant in time given defined parameters. If the parameters are not correct or an insufficient number of iterations are run, then the result will not be the best F-F. A quantum computer, with its essential advantage of being able to simultaneously study virtually all possible alternatives from the system's decomposition of top-down, bottom-up, lateral and blended F-F concepts in a tractable time period, gives rise to a normative method or tool for choosing the best concept.

In product development the system must be decomposed into its functional elements for detailed functional descriptions and requirements. The system is not merely rolled up into a final form-function design since the decompositional study tends to be too isolated and deprives the opportunity to combine sub-functions together and combine F-F at higher levels. It has been stated in various learned papers that the product development process should start with the decomposition and then proceed in a top-down and bottom-up design set of alternative design studies until a winning concept emerges. Many times concepts suffer from the existing paradigms of the inventor's or company's culture; even diverse teams' strong opinions tend to dominate the concept selection process. Such team members may have or desire political power,

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[97] Leveson, N.G. "Intent Specifications: An Approach to Building Human-Centered Specifications," *IEEE Transactions on Software Engineering*, Vol. SE-26, No. 1, January 2000.
[98] Clockspeed, Charles H. Fine, 1998, Perseus Books.

or just have dominating and possibly alienating personalities. Time and budgets may force concept freeze decisions to be made too soon as well. Furthermore, the decomposition and aggregation approaches, although improving, still suffer from too much sequential activity. Ideally, the system concepting is a process of simultaneously considering all (or probabilistically all) functionally different solutions by combining individual requirements with other functional requirements for structural concept definition, while simultaneously considering all (or probabilistically all) form-function possibilities.

In considering the idea of simultaneity in combinational F-F design, it is possible that a simplified algorithm could accomplish this task since otherwise the computing power of classical computers would be too limited. A quantum computer would be very useful since it has as its key attribute the ability to compute on multiple paths simultaneously, to act as a virtual reality generator to simultaneously consider both individually, micro and macro F-F, and integrated F-F solutions, and to provide a final recommended concept, system architecture of a product along with extensibility for product family growth and evolution. The current concern of errors in quantum computing because of decoherence might actually serve to benefit the concept designer by providing different virtual concept answers for each algorithmic execution. Different concept solutions might assist test marketing to match psychological desires and preferences with the form-function solutions. A quantum virtual reality computer should remove the paradigming flaw in product development. However, if the algorithm has too restrictive rules, it will act like a paradigm boundary limiter to creative solution providing. The simultaneous processing of quantum computing should act like the human mind to approach the ideal holistic design concepting consciousness.

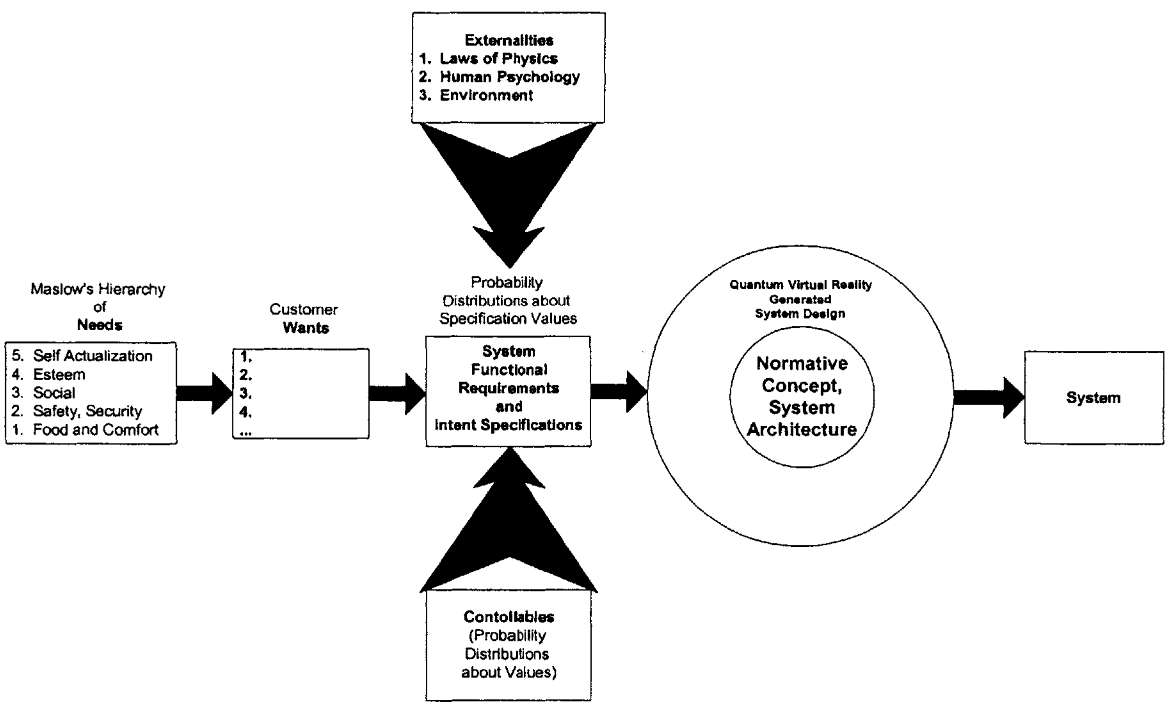

Figure 11.2 Parameter Diagram of the Quantum Virtual Reality Generated Normative Concept, System Architecture

Another depiction of the F-F in a flow diagram using Object-Process Methodology is shown in Figure 11.3.

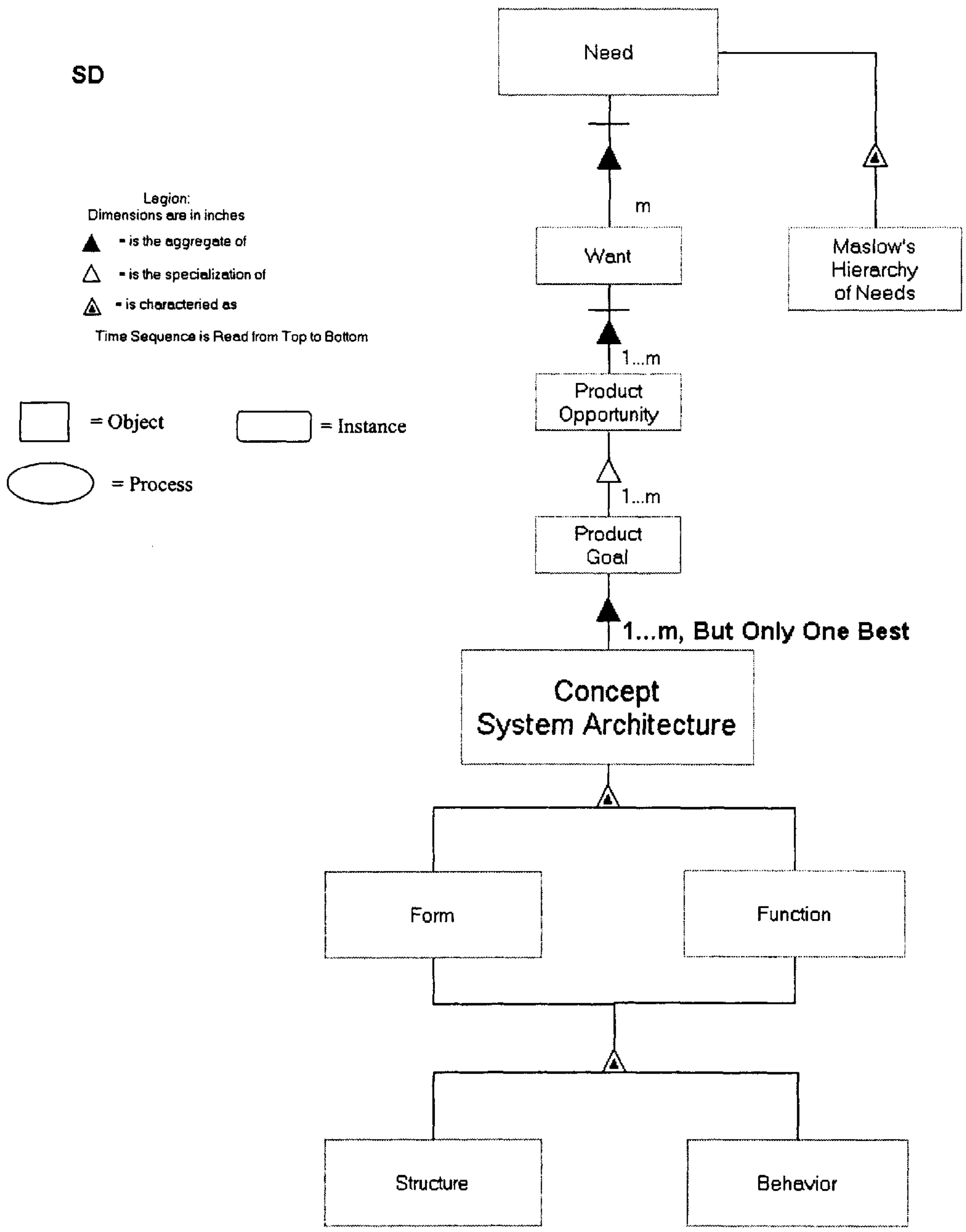

Figure 11.3 Form And Function (F-F) Flow Diagram using Object-Process Methodology

Nature's Varied Processes of Creation, Function and Form

This section starts from the beginning of time and creation describing nature's self-generating and evolving F-F. Thinking about nature's evolutionary process can give rise to the development of a creative, yet normative process in guiding the dance between function and form in new product concept development. The system architecture algorithm described subsequently is derived with nature's self-generating processes in mind.

In the beginning of time there was pure energy. Matter could not exist because of the initial extremely highly concentrated and hot condition of the big bang. Once this encapsulated energy burst its compressed state, expansion and cooling started immediately. The chaotic process coupled with uncertainty and least action principles started the creation of what we call the universe. Energy formed into the basic things called quarks, and these quarks are held together by other forms of energy called gluons. As cooling continued further, clumping of energy allowed quarks to come together to form nucleons and electrons. Chaos and nuclear forces of attraction permitted clustering of nucleons and electrons to produce elements. The elements could bind together into molecules according to chaotic action and opposite polarity attraction. The first element coming into existence was hydrogen, the most basic of all the elements requiring only one electron and one pair of nucleons. Then there came helium with two electrons and two pairs of nucleons, then carbon, with six electrons and six pairs of nucleons, nitrogen with seven electrons and seven pairs of nucleons, and oxygen with eight electrons and eight pairs of nucleons. The cooling process and the condition of cooler pockets or regions in the universe transformed localized energy into clusters of particles called nebulae. This energy-matter cloud collapsed over time under attractive forces until such a concentration or density was reached that a resulting nuclear fusion reaction ignited into stars. In chaos certain shapes, particularly the spiral, show up as a common form such as seen in planetary solar systems and star clustering galaxies.

The earth was created from a supernova and the attraction of our local star, the sun. At the beginning of the earth's evolution, the earth's core temperatures caused by the density of gravitational forces created volcanic eruptions at the surface of the planet, releasing methane gases (NH_2) into the atmosphere. Also, nitrogen oxide (NO) and hydrogen oxide (HO) formed in the atmosphere and condensed sufficiently to fall by gravity to the surface of the planet, accumulating as liquid oceans of methane. Lightening strikes in the atmospheric plasma of methane and the sun's energy in a chaotic process permitted an evolutionary progression to develop life. In the early stages of the earth's formation, electrical storms caused a fascinating dance of these basic elements in the atmosphere and on the surface of the Earth. The closeness in form of carbon, nitrogen and oxygen causes one to speculate that hydrogen jumped between these elements in its attachment to create increasing volumes of carbon, nitrogen and oxygen molecules. As time proceeded, more and more hydrogen and oxygen combined as water, began to form in clouds, and then condensed, which displaced the methane oceans with water. Increasing electrical storms and volcanic eruptions caused further chemical chaos, which eventually formed amino acids.

Further chaotic behavior of the amino acids produced DNA and RNA. The interesting consequence of DNA/RNA is that it follows a Monte Carlo means of determining the outcome of F-F. This Monte Carlo based decision-making process served as the germination of life. As life began to form into greater complexity from the original monocellular form to multicellular form, with its specialization of certain cells and functions in an integrated living system, the phenomenon of Darwinian natural selection provided a further perturbation to the Monte Carlo decision-making process. The filtering out of living evolution by the survival of the fittest favored the evolutionary path of environmental adaption and intelligence, that is the ability of the living system to make a choice among alternatives for its basic need of survival including the procreative drive, and then its search for fulfillment of purpose and search for meaning. Could the formation of the universe and its chaotic attraction of energy have developed different forms of nature? Could the universe have progressed in any other manner, probably not appreciably different. If one analyzes chaotic behaviors, there is a self-organization by repetition of form and an infinite level of replication.

Newtonian physics is a milestone achievement in the understanding of reality by drawing on observations of materials and machines, that which is known through our visible senses, to develop theories of how the universe works. There is more focus recently on design of systems by understanding the whole rather than focus on the parts – the holistic view. System dynamics[99] is one of the first attempts to create models of entire systems which emulate past and present system behavior and serve to predict future behavior. By means of these models it is possible to see system behavior and its forms.

James Maxwell achieved another critical level of understanding in physics by bringing together four equations for a complete description of electromagnetic behavior. This step was an important break from just the material world to include that which is unseen, yet exists. Einstein significantly altered our understanding of reality in first his special relatively theory, which connected Newtonian mechanics with electromagnetics to show that not only were Newtonian laws incomplete, but that there was a connection and actually a state difference between energy and matter and that matter moving at the speed of light becomes pure energy. The reality of spacetime was also described by Einstein. Eleven years later Einstein broadened our universe reality by showing the equivalency of acceleration and gravity. Gravity forms the geometric fabric in space, creating form by its attractive process. Niels Bohr, one of the fathers of quantum physics, and Werner Heisenberg showed that reality is uncertain, and at the subatomic level prediction of article position and momentum simultaneously is impossible because both are uncertainties. In high-energy states matter and energy dance between their states and are essentially the same, coexisting in a plasma. Matter is energy in a different form. Subatomic particles of matter have unseen connections with each other and by their overlapping and combining determine the texture of the whole.[100] These connections are the fundamental stuff of all creation.

In biology holistic dynamic modeling is helping to understand the machinery of life. The neurological, endocrine and immune systems once thought of as being discrete systems are now better understood as one system of interdependent functionality.[101] The dynamics of living systems, disorder and change can cause the system to reorganize into a new form of being. At the chemical level some systems self-organize themselves differently in an adaptive process to environmental changes.[102] The current terminology used for the system being taken out of equilibrium is the disruptive process. Order and chaos are being considered as symmetries of each other. The system in a chaotic unpredictable state can become orderly by the introduction of boundary conditions. Chaotic states are essential to the creative process just as boundaries to the system are essential to new create order.

Space is not a void or vacuum. Einstein may have shown that ether does not fill space, but instead invisible fields of forces exist within space and shape the behavior of everything. These

[99] Industrial Dynamics, J. Forrester, MIT Press, 1961.
[100] Physics and Philosophy, Werner Heisenberg, New York: Harper Torchbooks, 1958.
[101] The New Physics of Healing, Deepak Chopra, Boulder, Colorado, Sounds True Recording, 1990, audio cassette. And, The Ages of Gaia: a Biography of Our Living Earth, James Lovelock, New York, Norton, 1988.
[102] The End Uncertainty: Time, Chaos, and the New Laws of Nature, Ilya Prigogine, New York: the free press, 1998. And, Order Out of Chaos, Ilya Prigogine and Isabelle Stengers , New York: Bantam, 1984.

fields are unobservable and serve as non-material, influential systemic effectors. Transformational processes within fields are fluidic and dynamic, ever-changing. The forces we can see also affect human behavior, which is guided by individual and special interest group needs and wants. Forces control the form of organization of structure, both externally and internally. The external may be considered the collection of the market space, investment space, and culture. Feynman diagrams and S-diagrams depict the network of interrelationships among particle states, represented by lines of their kinetic energy interacting and manifesting into different forms of energy. These diagrams show the transformations in the forms of emergence, decay, and new forms of high-energy state particles. This interactiveness of energy forms can be viewed as a network of structural processes of potential and actual creativity. Since space is constantly creating, continuously changing, then possibilities and potentials abound to the infinite. One might say that the idea of "truth" exists only for a moment in time. Any one solution to the best concept for a product is only for a moment in time, given the freezing of boundaries, form-creating constraints. The truth and the best concept are continuously morphing. The best products must have an ability to continuously change within the competitive market space. Equilibrium in physics and social sciences is a state that all systems continuously strive to attain. However, the paradox is that in self-organizing systems, there is the process of creation, change, and new form generation. Interestingly, both chaos and equilibrium are described by the Second Law of Thermodynamics. Systems seek a state of maximum entropy and chaos within open space and develop an equilibrium state of order within the system's boundaries. A product concept can be viewed as a system having reached its equilibrium state of form and function. Life is a continuous evolutionary process of birth, destruction and rebirth through continuous, selective adaptive morphing. This natural evolutionary process applies to both biological function-form and social function-form, where change is an inevitable part of the creative process of selection and adaptation for survival. The study of system dynamics shows the necessity of feedback loops which insure in life forms the ability to adapt and change. Disequilibrium is essential for a system's growth. The paradox of nature is that function and form is constantly self-destructing and regenerating itself in new variants of function and forms.

Belousov-Zhabotinsky demonstrated a certain chemical reaction in response to temperature change that forms swirls in a spiral similar to the formation of galaxies. Others have noticed this basic form of natural design.[103] As stated by physicist David Peat, "could such a collective wisdom perhaps be expressing its intuitions of the wholeness within nature, the order and simplicity, chance and predictability that lie in the interlocking and unfolding of all things?" The universe is a self-organizing system that creates structures at that moment. The creative process within the structures of the universe is constantly reorganizing into different forms of order depending on surrounding force fields. The earth as a Gaia powerfully demonstrates how a system within the universe in a relatively open environment and using self-organizing system dynamics can develop an increasing autonomy for its coexistence with the environment as well as internal self-sustaining processes. One also can notice this self-organizing drive in the form of organization processes, which serve as a means whereby a system in itself can attain stability over time. Externalities to the system cause changes in a random yet patterned behavior, by which the system must adapt itself and become robust. Jantsch notes that "the more freedom in self-organization, the more order."[104] "Evolution is the result of self-transcendence at all levels.... [It] is basically open. It determines its own dynamics and direction.... By way of this dynamic interconnectedness, evolution also determines its own meaning."[105] It might be pointed out that leaders who strive for equilibrium stability through their control of constraints on freedom are

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[103] The Philosopher's Stone: Chaos, Synchronicity and The Hidden Order of the World, David Peat, New York, Bantam books, 1991.
[104] The Self-Organizing Universe, Erich Jantsch, Oxford, Pergamon, 1980, p. 40.
[105] Ibid., p. 14.

actually preventing change and eliminating conditions which are necessary for the organization's survival.

Life is being considered as a predictable outshoot of the disruptive creative processes of inanimate system behavior. Of considerable interest is how a relatively simple formula, which actually serves as the boundary conditions of the system in computer generated plots, makes creations that have both chaos and order in their form imagery during their computer-generated evolution of form guided by, as some term, "strange attractors." Any one plot point is impossible to predict precisely, but looking at the system as a whole, it has a definite form emanating from the seemingly chaotic unpredictability. There is an inherent orderly dance. Oftentimes in the universe there is an outward complexity yet an inward creative simplicity. Also, there are categories of forms that repeat themselves throughout the universe, particularly swirling forms. Disorder and order blend together. Capra describes it as "dynamic patterns continuously changing into one another a continuous dance of energy."[106] With respect to perceived form "all of the wave function representing the observed system collapses, except the one part, which actualizes into reality."[107] At times we hear of the term critical mass applied to an organization's process condition and critical connectedness.

Closed feedback loops are necessary for a system to receive information for the selective adaptive process of survival. "In-formation" in this sense can be viewed as information.[108] Within closed feedback loops information comes in different manners as necessitated by the system for change information. Freedom of communication within the system provides the necessary fertility, stimulus for selective adaptive change. Information also creates an orderliness albeit in the form of a new order. This selective adaptive process may be a definition of intelligence. Using this definition, the universe has an innate intelligence. The universe is able to respond and adapt to changes within its environment. One might say that the greater the system's ability to respond to change, the higher its intelligence. "Innovation is fostered by information gathered from new connections; from insights gained by journeys into other disciplines or places; from active, collegial networks and fluid, open boundaries. Knowledge grows inside relationships, from ongoing circles of exchange where information is not just accumulated by individuals but is willingly shared. Information-rich, ambiguous environments are the source of surprising new births."[109] When does information have meaning to constitute a change force? Systems must themselves sense certain types of changes (filter out unnecessary random information) in the potentially disruptive environment in order to undergo systemic change. There is a type of selectivity of information for the system's survival. The more adaptation a system undergoes with respect to its environment, the more robust it becomes. Fractals are a form of the evolving feedback (or information) in equation form, with every new solution iteration developing over time complex and repeating patterns to infinity. The nonlinear equation sets the boundaries of the evolving system usually in a rather simple statement.

If one could specify statements of a system product's intent in a simple set of equations, it might be possible to computer generate an evolution of the function and form of a product. We must understand the interplay between the system dynamics and its subsystems, which is a discovery dance that requires several iterations between and among the whole and its parts. The product reality is created through its participation of customers who choose what to notice, things to include, and which to ignore. It is by the selective perception that the product and market are co-creative. "I am both astonished and confident that, as quantum theory and biology teach, no two

[106] The Turning Point: Science, Society, and Arising Culture, Capra, New York: Bantam, 1983, p. 91.
[107] The Dancing Wu Li Masters, Gary Zukav, New York, Bantam, 1979, p. 79.
[108] Leadership and the New Science, Discovering Order in a Chaotic World, M. Wheatley, Berrett-Koehler Publishers, 1999, p. 96.
[109] Ibid., p. 104.

people see the world exactly the same."[110] Biology and any living network using the profound strategy of natural selection and adaptation should be able to determine the best form and function given boundary constraints of the system.

Chaos is a turbulent state with unpredictable local outcomes. However, these outcomes can create a predictable form. This paradox of chaos and order is possibly at the core of the universe, but also more specifically in new product concept creation. Seemingly randomly positioned points after many iterations create a pattern of form which very often are pleasing to the perceiving mind. In system dynamics a system may become oscillatory, and over time patterns of the oscillations or combinations of oscillations among subsystems reveal themselves. As order emerges out of chaos, there develops a boundary that exists within the system which determines the forms after the system's feedback loop cycles many times. To see the pattern one must study the system as a whole and not its individual parts in an isolated manner. Studying the decomposition of a system and developing best functional solutions per branch of the decomposition creates a suboptimization and not necessarily a total system best solution. In physics the principle of least action suggests orderliness out of apparent random fluctuations in the universe. Fractals in fact are natural patterns which can be simulations of clouds, nebulae, whirlpool spirals, galaxies, black holes, folds of the brain, and nervous system network forms – circular for a system, plants, genetic transformations, and many others. Fractals are complex yet emanate from simple equations. The details of how chaotic behavior create the form are not as important as the form itself. This is fortunate since no one really knows how form is created by these fractal nonlinear formulas. However, the study of our universe is occurring at two levels, the macro cosmic and the micro quantum levels. We must grasp both the macro and the micro together for a holistic systems view since all things are interconnected and inseparable.

Function and Form Alternatives

The idea of "dancing" or zigzagging between function and form is fascinating, like jumping to and from yin and yang, position and counter position, and provocation opposition. (See Figure 11.3 and 11.4, for the concepting of an automatic fastening system.) In fact, is this the way concepts develop? Should concepts be developed in this manner? After listening to an architect in a systems architecture lecture, it seemed that function drove form. In the case of the F117 could the form have been any other or did the stealth function drive the form? The two competing F22 and F23, and the two JSFs, seem to answer this question that stealth fighters can take different forms than the F117 (which was a bomber), but their functional missions are not identical. The stealth bomber, the B2, could it have been another better form? The blended body and wing creates a oneness of form and function. Is this then the best concept?

This thought process leads to the puzzling question which is, given the constant change with different clockspeeds[111] in technology and the ever increasing expectations of customers reaching for "Free, Perfect, Now,"[112] how does the architect know when he/she has the <u>best</u> concept? In January 1999 the SDM99 class had 6 teams "competing" to produce the best Mars land roving, data and sample collecting, and reporting system. Each team was convinced it had the best and only concept which could comply with the customer and technical requirements, yet on the Friday of the presentations it was discovered that each team had created a completely different concept, that each concept could satisfy the requirements, and that the best attributes from each concept could have been extracted to create a seventh and even better concept from the same basic materials. So, how do you know when you have the best concept? How can you compute a

[110] <u>Ibid</u>., p. 149.
[111] <u>Ibid</u>.
[112] <u>Free, Perfect, Now</u>, Robert Rodin, 1999, Simon and Schuster.

normative solution to concept creation given boundary constraints? Professor Suh[113] has shown an attempt to answer this question as does the TRIZ[114] approach. Such product concept development approaches and their lack of use in practice so far indicate that these endeavors are not yet practical normative solutions.

The concept creation forces of the electric servo controlled roller screw technology (Escrst™) automatic fastening product family development, described earlier, in fact do not show a dancing from function to form and from form to function. Instead a creative problem solving process is described where function in the end drives form.

How do you fit serendipity into this dancing method? Some of the most creative solutions to problems have been discovered by serendipity. So, how do you induce the studying of different angles of attack, of different perspectives to solve problems?

The dance seems to be between physics and form. Physics is the underlying basis of creative possible functions. For instance, into how many functions can energy transpose itself? Starting with the proper statement of the problem as the most crucial step in concept and product development, the basic physics of the problem must then be discerned. Understanding the physics allows a mind mapping or alternative creativity stimulating process to be used to compose different possible functional adaptations for solutions. These adaptations are abstractions in physics, which can then be used to develop forms. Form is the psychological interface with the customer. The functional solution then must be adapted to the form desired by the customer. In this sense the customer is the ultimate force which first wants the function satisfied and then wants the functions in a psychologically pleasing form. (See Figure 11.2 and 11.3) The study of nature creates scientific knowledge which is the basis of physics, which in turn by human ingenuity creates technologies and technological change, which provides functions from which form can be derived. Humans, customers, interact with nature through the human desire to satisfy their insatiable needs, and they develop wants for things which have form.

On the one hand certain Japanese companies, and Rubbermaid as an example in the United States, have used the approach of developing many products and forms and throwing them at the customer wall to see what sticks, as well as also creating ideas/ products that customers did not know they wanted, such as the Sony Walkman. The Swiss Swatch is another excellent example. Both Walkman and Swatch use a basic platform underneath a standard cassette tape player and quartz crystal chronometer, varying the exterior form to suit the customers. Ford and Toyota similarly provide different exterior forms with commonality of functionality underneath.

[113] The Principles of Design, Nam Suh, Oxford University Press, 1990.
[114] The Science of Innovation, V. Frey and E. Rivin, 1997, TRIZ Group.

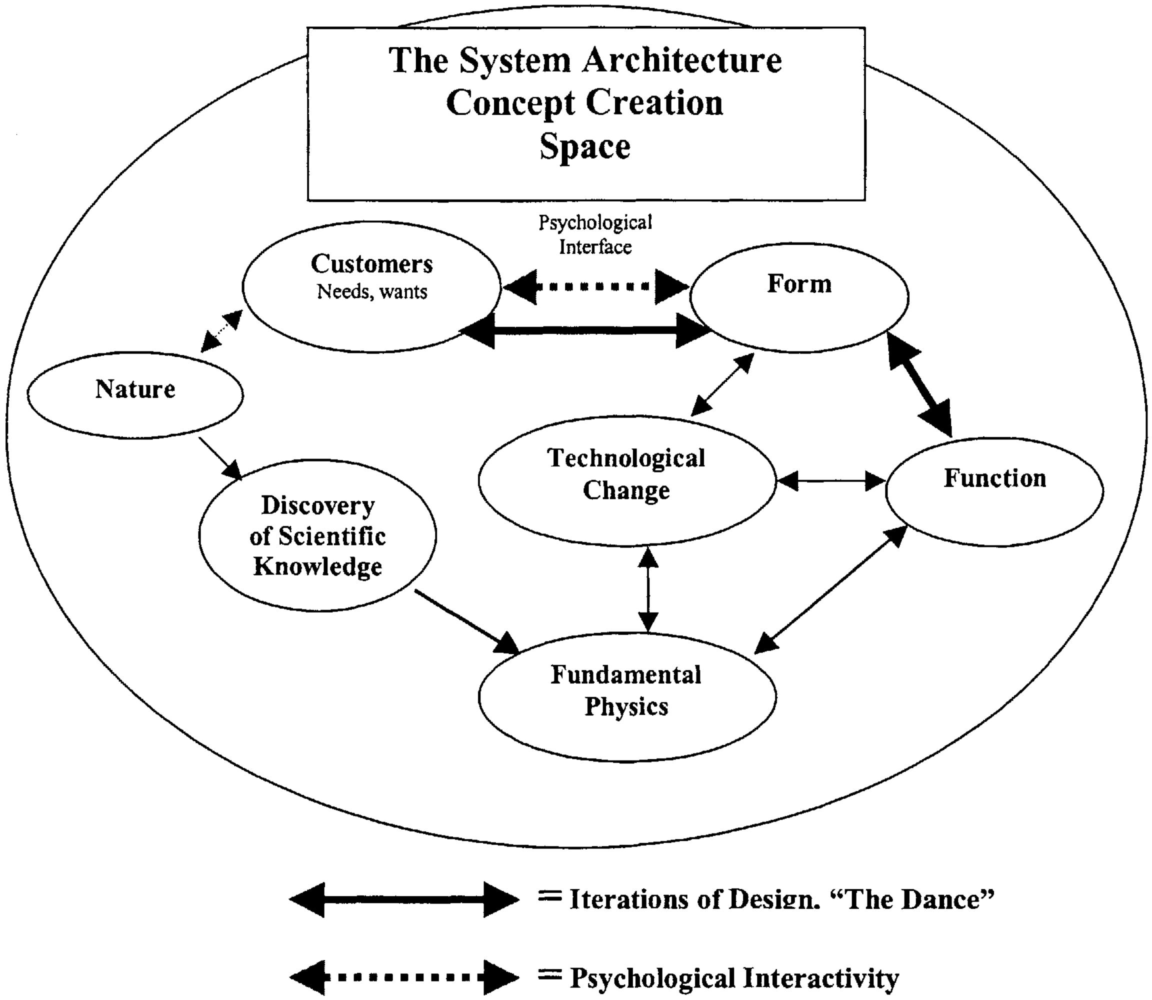

Figure 11.4 The System Architecture Concept Creation Space

In contrast, design concepting can be most deliberate. The SR71 started with the design physics of high altitude, Mach 3 velocity, drag, heat, photography; Skunk Works used a small cross-functional team tightly grouped together, hovering over a common layout sheet, which concurrently combined form and function using titanium as the basic building material. Says Ben Rich,

> "when suddenly I got the idea of unhinging the door between us, laying the door between a couple of desks, tacking onto it a long sheet of paper, and having all of us join in designing the optimum final design to make full use of the chines. My objective was simple. I said, 'We're never going to get this design a hundred percent right. We could play around forever. But I think we now know enough to nail it down at eighty percent. And that's plenty good enough."[115]
>
> "It took us a day and a half."[116]
>
> "Kelly kept those of us working on his airplane jammed together in one corner of our old Building 82. From the original four he had approached on this project, we had grown to a modest fifty or so, seated at back-to-back desks, where, like the early U-2 days, privacy surrendered to

[115] Skunk Works, B. Rich, Back Bay Books, 1994, p. 199.
[116] Ibid., p. 199.

> incessant kibitzing, teasing, brainstorming, and harassment. Some wag hung the sign PRIVACY SUCKS. My three-man thermodynamics and propulsion group now shared space with the performance and stability control people. Through a connecting door was the eight-man structures group, who designed the strength and load characteristics of the airplane."[117]

In the case of the F117, most customers did not like the "inelegant" form, but the function of stealth was satisfied and proved to be more important than form. The F23 was desired for its beautiful lines, but the F22 optimized all multi-customer wants. The Raphael was desired for its beauty over the EFA, but I think other countries' pride and politics prevented the Raphael from becoming the European Fighter Aircraft concept.

Dancing implies both freedom of style yet with some regularity of control. Thus, the concept composed of the combination of form and function uses the right and left hemispheres of the brain to form a holistic Gestalt or mental picture.[118] For concept development it is useful to review many divergent notions of F-F alternatives and with movement thinking go down the path of usefulness, analyzing the advantages and disadvantages of each alternative in the short run and the long run. Furthermore, it is useful to converge these alternatives, to learn the best alternatives of each one, if possible. There are creative techniques to stimulate the dance, such as, lateral thinking, "PO" provocation: equal and opposites, reversals, the creative pause, exaggerations, distortions, wishful thinking[119], daydreaming, mind mapping, blank sheet approach (tabula rasa), normative approach, six thinking hats approach, and use of random words as a starting point[120].

Gemcor handles many types of requests for proposals/projects on a continual basis, which requires constant developing of concepts. As learned from the January SDM99 project team experience the team members study the "problem," develop their own understanding of the problem as well as F-F concept solutions independently, and then bring them back to the team to discuss the pros and cons of their alternative conceptual ideas. The team analyzes the problem statement with respect to the different interpretive understandings individually conceived, which usually improves the problem statement. Then the F-F concept alternatives are analyzed, and finally the team decides on the F-F concept.

The concepting seems to be a much more complex process than just the "The Dance" between F-F. Concepting is a set of simultaneous functions that must be solved, which today is done in a heuristic manner because we do not have a set of rules or laws to determine the different possible concept varieties, alternatives among customer preferences, F-F's, and available technologies along with physics to algorithmically define the concept. Nor is there a computational method today to solve such simultaneous functions efficiently and timely. One day with rule based programs and very fast computation, there may be a way to do such conceptual analysis and decision making similarly to the deep blue chess playing computer/ software system.

Returning to the earlier question, how do you know when you have the best concept? How can a methodology be developed to determine the best design concept? As is now known, the concept drives approximately 80% of the success of the product or system. Therefore, it is of utmost importance that the concept be the best before any other scarce resources are expended. Efforts to address the best solution determination have included: choose a single idea which comes to mind,

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[117] Ibid., p. 201.
[118] The Mind Map Book, Tony Buzan, Plume/ Penguin, 1996, pp. 32-36.
[119] Serious Creativity, Edward De Bono, APTT, 1992.
[120] Ibid.

trial and error, development of a limited number of alternatives and select the best, design matrix structures, and axiomatic design[121]. Axiomatic design is a worthy attempt but only a start as its creator actually encourages us to find better ways to determine the best design. Axiomatic design can be difficult to apply and does not necessarily yield a best solution. The flying or blended wing aircraft design is a case in point. Axiomatic design would advise a separation of wing and fuselage. However, Jack Northup's 1929 concept of combining the two yields a very efficient design which combines functionality with a pleasing form. In this case the axiomatic theory of best design determination has broken down. Why? Are the laws of physics a form of perfection? Is nature perfect? Is the adaptive process in physics, as well as selective and adaptive nature, the means to create the best design albeit over very long periods of time relative to the short life cycle of humans? Could the parameters of the system be determined, and then a speeded up least action and adaptive process be used for a system to self-organize the best design? It is possible. Looking at the universe and its design, it is self-organizing only by the physical laws with no other constraints. There is no best way in its make up and form, it exists as it is. Yet, there is a process ongoing. Natural selection has added the independence and also societal nature of life matter, and the adaptive process for life has a purpose – survival. One might wonder, if the universe is a system, then what is its function/role?

The Quantum Algorithm for Determination of the Best Concept

The current selection procedures and determination of the best product architectures are flawed. The methodology is characterized by a trial and error process influenced by emotion. Regardless of the sometimes best efforts to study alternative concepts and determine an optimization of all upstream and downstream influences, the present method does not consider all different concept possibilities. The quantum computing power based upon its processing simultaneity capability along with a proper algorithm can provide such a method and during the best design determination remove the emotion from the process. This is not to assert that emotion is not important, in fact, it is a vital ingredient to fulfilling the satisfaction of the customers' wants. In the end it is the customer who decides of course which products succeed and which do not, determining the successful system architecture, and this decision could be unduly weighted by emotional/aesthetic preferences. On the other hand, if the customer has the facts that all alternatives have been studied (by the quantum computer) and is provided with the reasons for the final recommended system, the customer may more likely accept the design concept. Customers also have the desire for distinction, that is differentiation from others, or belonging to different classes. Otherwise, everyone would be forced to choose the only one best solution as Henry Ford had accomplished for a time with his black color only Model T Ford. This leads to the subject of platforming. "Underneath" the design can be the best design concept but its exterior form must satisfy the customer's psychological wants. Given the existence of a quantum computer, differing customer psychological makeup's could be categorized and used as constraints in determining the differing form solutions given the functional best concept platform.

[121] Suh, op. cit.

- Building Architecture
- Genetic Structure and Architecture
- Machine Tool Architecture
- Airplane Architecture
- Automotive Architecture
- Software Architecture
- Accounting Services Architecture
- Business Organization Architecture
- University Architecture
- Banking Architecture
- Space Vehicle Architecture
- Furniture Architecture
- Sport Architecture
- Recreational Architecture
- Telecommunications Architecture

Figure 11.5 Various Types of System Architectures the Virtual Reality Quantum Generator Must Solve

The customer needs and wants must be studied and statistically determined as a key parameter input constraint to the quantum virtual reality generator of system architecture. However, given the customer want input, a normative solution of the system architecture can be determined by the problem solving algorithm which simultaneously examines all the system's compositional F-F permutations and combinations. The computation starts with the determination of the least action physics solution satisfying the functional requirement constraints and then followed by the form requirement constraints. In this computative manner all decompositional and aggregational permutations and combinations can be examined to determine the best form-function solution. In the parameter diagram, Figure 11.2, the input is the want definition with the laws of physics, human psychology, and environment as variable externalities and all other variables as controllable and to be used to determine the normative solution of the system architecture.

It should be possible using a quantum computer to evolve, with a virtual reality generator, a form-function by means of DNA and genetic algorithms, then to analyze these different form-functions guided by a set of rules which are the intent specifications and the laws of physics. The algorithmic/ heuristic search is for the form-function that best satisfies the intent specification and is the least action solution.

The Introduction of Genetic Methods to the Quantum Computation

The product development problem is one of how to create a complex form-function that is successful in the marketplace.

The product is like an organism struggling for survival in an environment. Organisms of like species mate and share F-F attributes. How can we in a simulation cause the mating of F-F of different yet related types (species) to create new F-F? Then how can we test the new F-F with respect to the environment and the marketplace to see if it is better suited? The organism's genetic code has no planning but it has a history of F-F to build upon and which dominates the new F-F. Only environmentally caused and random changes in the code alter the structural basis of the F-F. In organisms the combination of gamete mixing of male and female and infrequent and subtle code changes produce a F-F which is tested over time with respect to the environment and of which the most successful survive – evolution. The marketplace is the realm in which a product's survival is tested. Designers and business persons constantly adapt both the product and the process to sell the product to make it successful.

Other than the survival feedback relevant to the ability of the organism to successfully continue to breed, there is no apparent planning in the genetic process. Similarly to inorganic nature the organism seems to merely exist yet in a dynamic and evolutionary manner. After all, the animate objects did evolve from the inanimate. Like living things, products have a lifecycle characterized by the S-curve of units sold over time until the product is substituted by some other better product/technology. Humans are beginning to understand the genetic workings to produce clones, and certainly sometime in the future organic replacement parts will be manufactured, and new improved organic systems will be planned and developed by human ingenuity. Genetic methodology might therefore serve as a model to make better, more successful products for the betterment of mankind.

In the algorithm below, at the point the coupling strength is developed the gamete attributes of both F-F are in a sense "mated" to create the new F-F. The boundary conditions are the combination of the marketplace and the environmental factors assuming they are properly described. The algorithm is constrained to work under these conditions.

How is the equivalent of change in the genetic coding introduced? One way would be to make random suitable changes in the marketplace, environmental boundaries by changing the intent specification. In this manner the coupling attraction among function variables may be allowed different degrees of freedom, and a different least action solution is developed. The random fluctuation could be done by Monte Carlo methods. The marketplace and environmental parameters can be represented as probability distributions. The randomness can be introduced by doing a Monte Carlo simulation of the stochastic boundary condition parameters. The least action solution is then a representation taking into account random fluctuation of the boundary parameter fluctuations as prescribed by the system architect and his/her team; skewing of the probability distribution shape can be done where appropriate.

How is the form, the human psychological interface with the product, fitted with the function? In genetics the F-F is imbedded in the code. Form has a definite role in the attraction process to mating. In the marketplace form attracts the customer as well as function for want satisfaction. Form and mating preserve the continuance of the species. How can we automate the virtual form generation which will succeed in the virtual marketplace, environmental boundary space? What if certain forms are more attractive to the marketplace but are not the least action solution? Quite possibly the least action F-F is the most psychologically pleasing form. Perhaps the least action F-F is based on such a phenomenon as ϕ, the golden mean, found in most F-F throughout the universe. Even in music there seems to be a blend of sound that is pleasing to hear, especially natural sounds filled with emotion, which too may be some form of least action to our consciousness.[122]

In light of the foregoing discussions on nature's self-generating processes, the algorithm to emulate nature's formative creative process is now presented with the perturbing of intent specifications, from which a normative product system architecture can be derived automatically.

[122] Examples are numerous but a few are Mozart the second movement of *The Requiem*, Beethoven *Symphony No. 6,Pastoral*, Ralph Von Williams *Fantasia on a theme by Thomas Tallis*, and Samuel Barber *Adagio*.

The Algorithm of the Normative System Architecture

Definition of the Normative System Architecture:

The Normative System Architecture is the conceptual solution having the least action.

Definition of the Least Action:

The least action is the conceptual solution having the least energy expended.

Definition of the Least Energy:

The least energy expended is the minimum effort upstream and downstream to simultaneously satisfy the design and environmental constraints, and produce the product at the least cost given the boundary constraints, in the least time-to-market.

Sequence	By Whom or By What Means
1. Conduct and quantify a needs/wants assessment of the market place, the customer	Team led by the System Architect
2. State the problem to be solved	Team led by the System Architect
3. Develop a statement of intent as a set of boundary conditions which may or may not specify a system architecture approach. State any preferred technologies.	Team led by the System Architect
4. Describe the basic fundamental physics to be satisfied by the system architecture	Team led by the System Architect
5. Decompose the problem into its basic fundamental physics	Quantum computer or high speed parallel processing computer
6. Determine different solutions to each decompositional element a. Database search of solutions to different physical problems, intranet (PDM) and internet b. Tie-in to internet technological databases/datamine search engines, i.e. www.invention-machine.com,Cobrain c. Choose best solution, least action	Quantum computer or high speed parallel processing computer

7. Rollup (Aggregate) the decomposition a single level at a time and determine coupling opportunities of solution a. Database search of solutions to different physical problems, intranet (PDM) and internet b. Tie-in to internet technological databases/datamine search engines, i.e. www.invention-machine.com,Cobrain c. DSM analysis for closest connection determination of the multiple variables d. Combine decomposition levels in an aggregate solution if it is least action with respect to the decomposed least action e. Choose best solution, least action	Quantum computer or high speed parallel processing computer
8. Continue the aggregation level by level upward with least action solution determination at each level until the top level is reached	Quantum computer or high speed parallel processing computer
9. Iterative Monte Carlo Random Changes to Values in the Intent Specification	Quantum computer or high speed parallel processing computer Evolution emulator
10. The top level is then the least action solution or best system architectural concept given the parameter inputs to the system	Quantum computer or high speed parallel processing computer

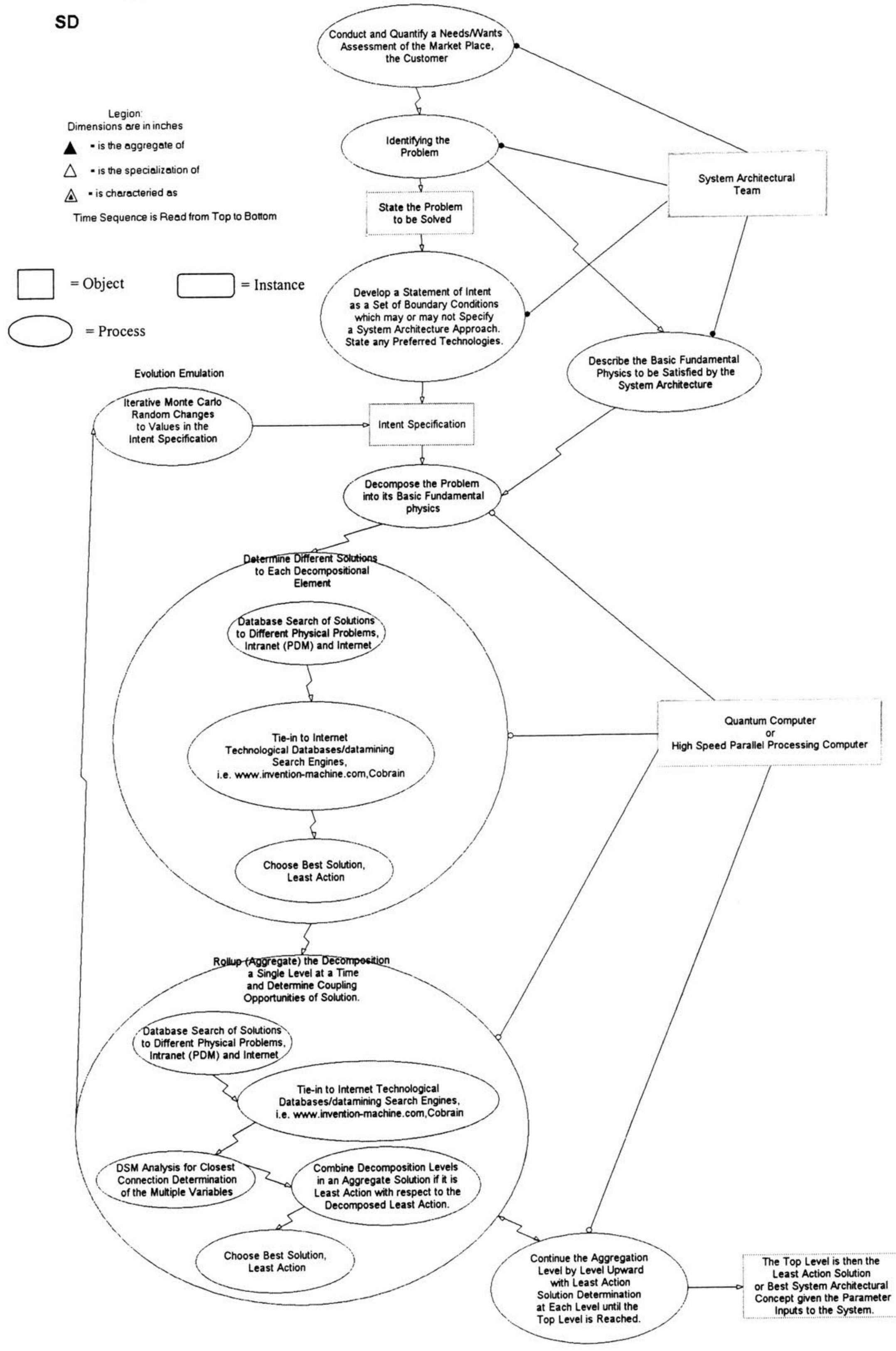

Figure 11.6 The Algorithm of the Normative System Architecture Object-Process Diagram

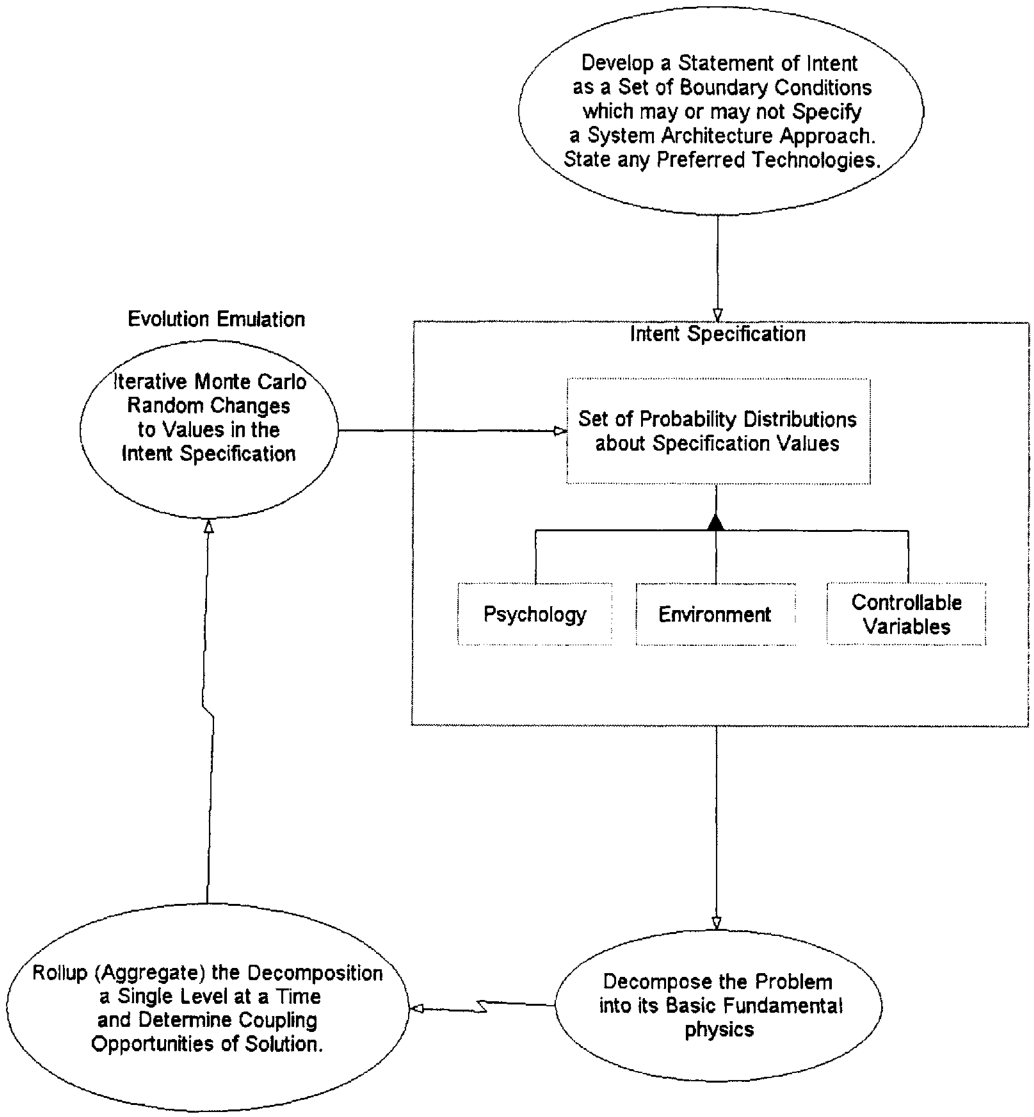

Figure 11.7 The Evolution Emulation and the Intent Specification Unfold Object-Process Diagram

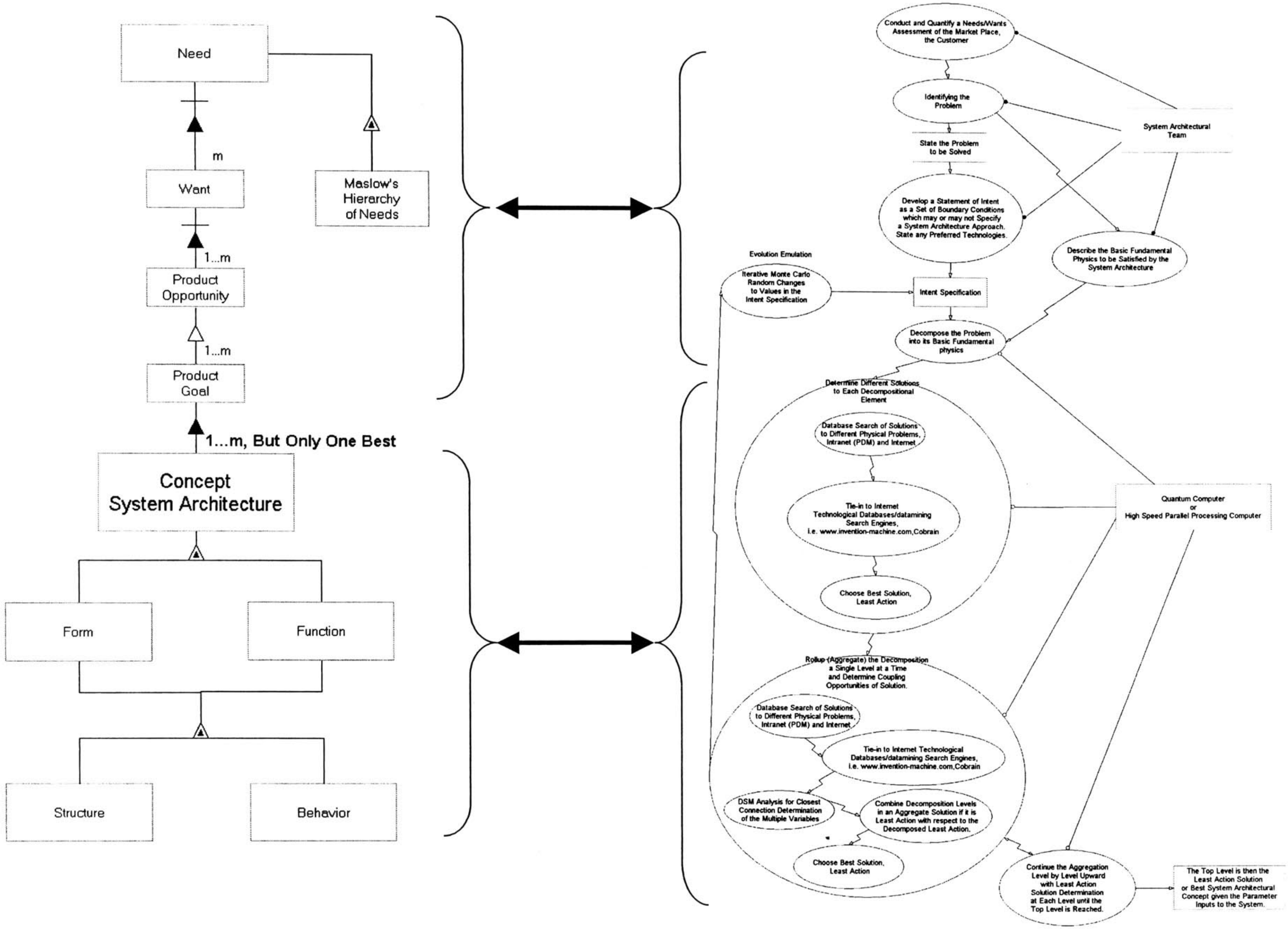

Figure 11.8 Further Depiction of the Normative System Architecture Object-Process Diagram

The Golem Project
In "Nature[123]," The Journal of Science, on August 31, 2000, researchers at Brandeis University published the status of genetically evolving self-generated robots. The name Golem comes from Jewish folklore and in this case stands for Genetically Organized Lifelike Electro Mechanics. After reading their paper and many of the web posted publications on the Golem website[124], it appears the convergence idea of physics, genetics, evolution and computation are common to some of the thoughts expressed in this thesis. However, their highly simplified tests on self-generating robots and Legos™ crane and bridge design and build are rudimentary and do not show a clear direction for practical use. The Law of Least Action was not mentioned in any of their work, but they seem to be trying to minimize energy in design and build. The evolved designs as they admit "look alien" and do not demonstrate design, F-F superiority.[125]

In another respect their work is appreciated since it reinforces the thesis here as not being science fiction. It is not clear why their research is intent on adding automated manufacturing to the design process nor why they are only considering robots. The self-generating of digital architectures is much richer in the complexity and variety, and it is not necessary to completely eliminate human involvement. The Golem work involves the co-evolution of the robot and the software control which is very interesting conceptually. Is it necessary to create the software for an integrated hardware-software system at the point of system architecting? Can software architecture influence the hardware architecture? The answer is yes to both questions. The software and control hardware are highly coupled in their design. Object-Process Methodology (OPM) assists in co-designing the software with the hardware. The OPM can document the intent specification and software, then it can serve as the means to describe instructions in semantic and syntactic terms, values, and conditions to the quantum computer.

Although the results in Golem so far are disappointing, they are plowing a path that will motivate others to find a better way, perhaps in nanofabrication and nanoassembly of self-generating objects possessing utility.

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[123] Lipson, H. & Pollack, J. B. *Nature* **406, 974-978** (2000).
[124] http://golem03.cs-i.brandeis.edu; also, see http://demo.cs.brandeis.edu
[125] Funes, Pablo, Lapat, Louis and Pollack, Jordan B. (2000). **EvoCAD: Evolution-Assisted Design**. *Artificial Intelligence in Design'00 (Poster Abstracts)* Key Centre of Design Computing and Cognition, University of Sidney. pp 21-24. And, Pollack, J. B., Lipson. H., , Ficici, S., Funes, P., Hornby, G. and Watson, R. (2000). **Evolutionary Techniques in Physical Robotics**. Miller, J. (ed) *Evolvable Systems: from biology to hardware; proceedings of the third international conference (ICES 2000).* Springer (Lecture Notes in Computer Science; Vol. 1801). pp. 175-186. And, Funes, P. and Pollack, J. (1999). **Computer Evolution of Buildable Objects**. In *Evolutionary Design by Computers*. P. Bentley (editor). Morgan Kaufmann, San Francisco. pp. 387-403. And, Blair, Alan D. , Sklar, Elizabeth and Funes, Pablo (1998). **Co-evolution, Determinism and Robustness**. In *Simulated Evolution and Learning (SEAL-98).* Lecture Notes in Artificial Intelligence 1585. Bob McKay, Xin Yao, Charles S. Newton, Jong-Hwan Kim, Takeshi Furahashi, eds., Springer-Verlag. And, Funes, P. and Pollack, J. (1998). **Evolutionary Body Building: Adaptive physical designs for robots**. *Artificial Life* 4: 337-357. And, Funes, P., Sklar, E., Juillé, H. and Pollack, J. (1998). **Animal-Animat Coevolution: Using the Animal Population as Fitness Function**. Pfeifer, R. et. al. (eds.) *From Animals to Animats 5: Proceedings of the Fifth International Conference on Simulation of Adaptive Behavior* . MIT Press. pp 525-533. And, Funes, P. J. and Pollack, J. B. (1998). **Componential Structural Simulator**. Brandeis University Department of Computer Science Technical Report CS-98-198. And, Juillé, H. and Pollack, J. B. (1998). **A Sampling-Based Heuristic for Tree Search Applied to Grammar Induction**. *Proceedings of the Fifteenth National Conference on Artificial Intelligence* , Madison, Wisconsin, July 26 - 30, 1998. And, Funes, P. and Pollack, J. (1997). **Computer Evolution of Buildable Objects**. *Fourth European Conference on Artificial Life*, P. Husbands and I. Harvey, eds., MIT Press 1997. pp 358-367. And, Juillé, H. and Pollack, J. (1996). **Massively Parallel Genetic Programming**. Advances in GP II, Kinnear & Angeline, Ed. MIT Press. And,
Juillé, H. and Pollack, J. B. (1996). **Co-evolving Intertwined Spirals**. *Proceedings of the Fifth Annual Conference on Evolutionary Programming*, San Diego, CA, February 29 - March 2, 1996, MIT Press, pp. 461-468.

Conclusion

The convergence of the laws of physics, genetics, evolutionary theory and computation provides a means of determining a normative approach to system architecting. The approach described in this section is the basic concept only. The actual development of the working machinery of the approach will require an enormous amount of detailed work and technique refinements, which would make for an excellent dissertation. Until a useful quantum computer exists, parallel-processing computers can approximate the normative algorithmic approach. Technical databases and datamining search engines are being developed and improved at a rapid pace. The linkage technique to these search engines should anticipate extensibility for easy additions. The usage of OPM will provide the means to transliterate the architectural team's market and product research requirements into semantic and syntactic system intent specifications. The object-process language can automatically generate the actual software code for the system. The OPM can provide the intent specification directly to the quantum computer. Furthermore, the OPM can accept random perturbations to the object values contained in the OPM, thereby emulating the evolutionary process and adding robustness to the derived system. The Golem Project at Brandeis provides credibility to the normative approach described herein although the approaches differ; they are both based on a similar convergence of the laws of physics, genetics, evolutionary theory and computation. The normative method described in this section is a 10-20 year look ahead of how system architecting might be accomplished to better serve the insatiable wants of the customer.

Appendix to Section 9

Model Variables, Equations and Units

SBU2 Satisfaction Factor=Quality of SBU2 Services*"SBU 2 Successful Orders Fulfilled %"fraction

Effect on Fraction of Customers at Risk due to SBU 2 Customer Satisfaction f([(0,0)(1,6)],(0,1),(0.7,1),(0.75,0.5),(0.8,0.15),(0.9,0.1),(1,0)) Dmnl

Effect on Time to Lose Customers due to SBU 1 Customer Satisfaction f([(0,0)(1,5)],(0,0.5),(0.25,0.6),(0.5,0.7),(0.6,1),(0.75,1),(0.9,1.5),(1,5)) Dmnl

Customer loss=Normal Fraction of Customers at Risk*Actual Customers*Effect on Fraction of Customers at Risk due to SBU 1 Customer Satisfaction f\ (SBU1 Satisfaction Factor)*Effect on Fraction of Customers at Risk due to SBU 2 Customer Satisfaction f\(SBU2 Satisfaction Factor)/Time to Lose Customers customers/Year"SBU 1 Successful Orders Fulfilled %"=0.9 fraction

Time to Lose Customers=Normal Time to Lose Customers*Effect on Time to Lose Customers due to SBU 1 Customer Satisfaction f\ (SBU1 Satisfaction Factor)*Effect on Time to Lose Customers due to SBU2Customer Satisfaction f\ (SBU2 Satisfaction Factor) Year

SBU1 Satisfaction Factor=Quality of SBU1 Products*"SBU 1 Successful Orders Fulfilled %" fraction

Normal Fraction of Customers at Risk=1 Dmnl

Product Retirement=SBU 1 Available Products w Service/Average Product Lifetimeproducts/Year

Product Transition=SBU 1 Available Products wo Service/Time to Develop SBU2 Services products/Year

Actual Customers= INTEG (Converting-Customer loss,"% of Total Potential Market that are Initial Customers"*Total Potential Market) customers

Service Retirement=SBU 2 Services for Discontinued Products/Time to Retire Services services/Year

Initial Available Products w Service=100 products

Services per Product Ratio=1 services/product

Satisfied Customers=SBU1 Satisfaction Factor*Actual Customers*SBU2 Satisfaction Factor customers

SBU 1 Available Products w Service= INTEG (Product Transition-Product Retirement,Initial Available Products w Service) products

SBU 1 Available Products wo Service= INTEG (Product Development-Product Transition,Initial Available Products wo Service) products

Customer recovery=Disgruntled Former Customers/Time to Recover Former Customers customers/Year

Customer Requests for Proposals=Satisfied Customers*RFP per customer Factor RFP

Disgruntled Former Customers= INTEG (Customer loss-Customer recovery,Initial Disgruntled Former Customers) customers

Initial Disgruntled Former Customers=10 customers

Effect on Fraction of Customers at Risk due to SBU 1 Customer Satisfaction f([(0,0)(1,1)],(0,1),(0.7,1),(0.75,0.5),(0.8,0.15),(0.9,0.1),(1,0)) Dmnl

Effect on Time to Lose Customers due to SBU 2 Customer Satisfaction f([(0,0)(1,6)],(0,0.5),(0.25,0.6),(0.5,0.7),(0.6,1),(0.75,1),(0.9,1.5),(1,5)) Dmnl

Service Development=SBU 1 Available Products wo Service/Time to Develop SBU2 Services*Services per Product Ratio services/Year

Normal Time to Lose Customers=10 Year

Service Transition=SBU 2 Services for Current Products/Average Product Lifetime services/Year

Potential Customers= INTEG (-Converting+Customer recovery,Total Potential Market*(1-"% of Total Potential Market that are Initial Customers")\) customers
Initial Services for Discontinued Products=10 services
Time to Recover Former Customers=2 Year
Potential Customer Concentration=Potential Customers/Total Potential Market Dmnl
SBU 2 Services for Discontinued Products= INTEG (+Service Transition-Service Retirement,Initial Services for Discontinued Products) services
SBU 2 Services for Current Products= INTEG (Service Development-Service Transition,Services per Product Ratio*Initial Available Products w Service) services
Product Development=Average Product per RFP*Winning Proposals/Average Time to Develop SBU1 Products products/Year
Initial Available Products wo Service=10 products
"% of Total Potential Market that are Initial Customers"=0.2 fraction
WOM Conversions="Contacts of non-customers with customers"*Fruitfulness customers/Year
Relative winning proposals=Winning Proposals/Customer Requests for Proposals fraction
Effect of relative winning proposals on fruitfulness f([(0,0)-(1,1)],(0,0),(0.05,0.5),(0.1,0.7),(0.125,0.75),(0.2,0.9),(0.25,0.95),(0.3,1),\(1,1)) Dmnl
Fruitfulness=Effect of relative winning proposals on fruitfulness f(Relative winning proposals)*Normal fruitfulness customers/contact
Sociability=0.5 contacts/customers/Year
"Contacts of non-customers with customers"=Potential Customer Concentration*Contacts with Customerscontacts/Year
Contacts with Customers=Sociability*Actual Customers contacts/Year
Converting=WOM Conversions customers/Year
Normal fruitfulness=0.333333 customers/contact
Total Potential Market=250 customers
SBU1 Concept Proposals=Customer Requests for Proposals*SBU1 Response Rate to Customer Requests RFP
Average Product per RFP=4 products/RFP
Average Product Lifetime=10 Year
Average Time to Develop SBU1 Products=1 Year
RFP per customer Factor=1 RFP/customer
Quality of SBU1 Products=MAX(0.8,SQRT(0.4)/0.9) fraction
Quality of SBU2 Services=SQRT(0.4)/0.9 fraction
Time to Retire Services=1 Year
SBU1 Response Rate to Customer Requests=0.5 Dmnl
Time to Develop SBU2 Services=1 Year
"SBU 2 Successful Orders Fulfilled %"=0.9 fraction
"% Winning Concept Proposals"=0.25 fraction
Winning Proposals="% Winning Concept Proposals"*SBU1 Concept Proposals RFP
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Simulation Control Parameters

FINAL TIME = 50 Year The final time for the simulation.
INITIAL TIME = 0 Year The initial time for the simulation.
SAVEPER = TIME STEP Year The frequency with which output is stored.
TIME STEP = 0.125 Year The time step for the simulation.