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Matching Product Development Practices to the Product Life Cycle

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The Commercial Aircraft Division of Northrop-Grumman, which is based in Dallas, was originally the Vought Aircraft Company. The seventy-eight year old company previously had been part of LTV and then Grumman Aircraft. Northrop-Grumman is headquartered in Los Angeles and has five divisions: B-2, Military Aircraft, Commercial Aircraft, Data Systems & Services, and Electronics & Systems Integration. The Commercial Division is increasing its share of total Northrop-Grumman revenues (from 40% historically to 65%). The company has chosen not to diversify into new businesses, but to shrink selectively, while emphasizing some core competencies. It has defense and commercial dual-use capability in Dallas, and has consolidated and co-located many functions, such as engineering, manufacturing engineering, quality control, quality assurance, and has moved them closer to the shop floor. Some major changes include reduction in several organizational layers and transition to full 3-D solid modelling via CATIA.

The CEO chartered a senior level multifunctional task force to develop policy and define the operating tenets of integrated product-process development (IPPD) at Vought. A major premise of IPPD is that focus is needed on both product and process. Functional processes are managed/improved within Process Management Teams (PMTs), but such processes are made operational by PMT members when they become members of co-located Integrated Product Teams (IPTs). IPTs and PMTs are interrelated and mutually dependent. IPT team members share responsibility for both product and process within teams. The IPT team leaders (End-Item Managers) focus on customer goals and cut across all functions to assure that customer goals are met.

The Commercial Division retained the program/function structure, but changed the role of functional management so that it supports IPTs. Cliff Harris directs the Vought Center in Dallas which is the home of many PMTs, and where a significant number of major processes have been consolidated. Gary Brown is responsible for the C-17 & Support Programs, and manages a set of IPTs that focuses on the C-17 product. Customers and suppliers also are members of IPTs. IPTs have responsibility for meeting budget, schedule, and product/process requirements. Accountability is based primarily on team performance, not on meeting any functional goals. The IPT team leader determines merit-based pay for team members whose time is assigned 50% or more to the IPT. Functional management is responsible for nurturing and developing the specialized skills of PMT members who are assigned to IPTs. PMT members are trained in SPC, Cpk, design of experiments, variance reduction, etc. Teams vary in size from five to dozens of members. Size seems unrelated to success in this Division. The biggest challenge is to get people who are used to individual recognition to share recognition as team members. Team evaluations are based heavily on survey feedback from internal and external customers.

PMT and IPT members are encouraged to develop their own plans and objectives, which are continually assessed for fit with the goals of the Division's seven-year long range plan and annual operating plan. Giving team members the bigger picture improves coordination between and within

the PMTs and IPTs in the Division. This also helps teams to modify and balance activities that change throughout the product life cycle. The contribution of engineering during the early life cycle stages is product design, but for mature products in late life cycle stages, the engineering contribution is sustained evolution and maintenance of the product. Support personnel appreciate better the nature of their evolving contributions when they are assigned closer to the factory, which is a general trend within the Division.

The benefits of IPPD have been substantial. Overall time to provide products to Boeing Programs has been reduced by 17%; time has been reduced in the C-17 Program by 14%. There was an improvement in cost per pound in both Boeing and C-17 programs in 1994. The amount of rework, repair and refabrication per standard hour in 1994 was reduced by 40% from 1993 levels. The first article inspection rate on the Gulfstream V was 89%. Finally, customer satisfaction has been very high. The Division was a Boeing President's Award Finalist and a McDonnell Douglas Preferred Supplier. It has received similar recognition on the B-2 Program.

Developing Regional Variations of a Successful New Product From a Common Platform

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The single-use camera business is growing more than 30% a year. From $5 million units in 1990, Kodak expects to sell $90 million units or $1 billion in sales by 1998. Fuji introduced the first single-use camera in 1987. Kodak responded quickly with its own single-use camera in 1988. By 1992, Fuji had developed a variety of innovative derivatives from its original platform, such as flash, telephoto, waterproof, panoramic view, etc. Although Kodak always was close behind, Fuji had developed five of the seven major innovations for single-use cameras.

Kodak was used to strong worldwide market share, with an especially strong position in the United States. The company had a strong functional structure and developed new products slowly. Strategy seldom developed from a business unit focus, but usually developed from "strategic silos," that is, senior functional managers issued directives to undertake projects from the perspective of their respective focus, e.g., reduce capital spending, increase revenue, etc. These silo-based initiatives tended to neglect the voice of the customer and to be heavily focused on the United States market. With the single-use camera market approaching $250 million in 1993, there was clearly a need for a business unit focus. Bob Laperle was appointed business unit leader for the development of a new generation of single-use cameras. Bob convinced the key 1,100 people working on a very successful project that continuation of the same strategy would put this product out of business by the year 2000. A differentiated product strategy and aggressive use of automation were needed to reposition the product as "value-branded."

Bob strongly supported the business unit concept, but believed that functions had an equally important role to play in the product's success. He supported the matrix structure concept, but thought that matrix structures often fail because their members lack clear "decision rights." These decision rights

include the right to: (1) decide the processes by which work will be performed, (2) develop options and make trade-offs within a process, (3) set goals for results that a process must achieve, (4) determine the evaluation system, and (5) allocate human and physical resources. Some decision rights belong exclusively to a group and others are shared. Functional managers have no decision rights in Business Unit decisions. They are invited to phase gate reviews, but do not make decisions. Their responsibility is to develop the expertise of their function-based personnel.

The Single-Use Camera (SUC) Business Unit was organized around the articulation of basic processes and the establishment of teams at natural boundaries between these basic processes. It was guided by eight Core Team members, some of whom were also Team Leaders for a specific set of basic processes; Product Design, Marketing, Continuous Supply (manufacturing and distribution). In turn, several temporary teams were formed throughout the product development cycle; Commercialization Teams (to commercialize a specific set of offerings), and Attack & Defend Teams (to meet a specific short-term opportunity). At the project's peak, 370 people worked in seventeen teams. There are now sixty people working in four teams. Many of the key team members plan to stay together to develop derivatives from the basic product platform. A second product platform "Leapfrog" has been working simultaneously on another platform that will supercede the one that is now ready for release.

The product development process includes seven phases and gates. Each phase has deliverables that must be completed before the team can move to the next phase. Members who traditionally have responsibility only in later phases participated in developing the product vision including styling, appearance, packaging, etc. Some initial prototypes were developed which consumers in six countries evaluated. Not surprisingly, consumers in different countries weighted appearance and features differently. Different camera designs and packaging will be sold in these different regional markets. The camera also was designed to appeal to the photofinisher who develops the film and sends the empty camera back to Kodak for recycling. A single-use camera may be recycled eight to ten times during its life. The plastic on damaged cameras is ground and remolded.

The camera was introduced last year in Japan. Manufacturing yield reached 90% within the first three months, with expectations that it will soon reach 99.5%. The camera is earning a 10% premium over current Kodak models in the United States and Europe. Two leading Japanese photo journals praised the camera highly. It has picked up new distribution channels in Japan. The camera has more than met the competition—it has beaten it!

Bob reemphasized that matrix structures can work when decision rights are articulated and accepted early in the project. Alignment of business processes, leadership, and teamwork contributes more to success than does structure. Kodak is still transitioning to a culture that is congruent with business teams. Marketing, for example, remains reticent about shifting decision-making authority to business teams. Business team members, in turn, are currently struggling to achieve the right balance between their work commitments and their personal lives.

Working Together: The 777 Design-Build Team Experience

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Boeing was working on a concept for a new airplane that was to be bigger than the 767 and smaller than the 747. The initial idea was to build a stretch version of the 767. However, Boeing's prospective customers did not express any interest in this. A small team conceived of a new airplane that would fill the niche between the 767 and 747. The team was authorized to approach the airlines and try to sell it. United Airlines liked the concept and agreed in October 1990 to buy thirty-four planes (with an option on another thirty-four). The 777 project team started design work in early 1991. The team set out to develop an airplane that would have the highest customer appeal and very high (98.5%) "dispatch reliability," which means minimizing repair frequency and repair time at the gate.

The maiden flight of the 777 was June 1995. There are now three planes in service. The plane is about the length of a 747 (209 feet, 1 inch), and holds between 325 and 400 passengers. The plane was flight tested for one year, which included testing whether it can take off and land with only one engine. Pratt & Whitney, General Electric, and Rolls-Royce each have developed engines for the plane. The plane has many innovations, all of which had to "buy" their way onto the plane; i.e., had to be cost justified. The plane includes some composite materials, flat panel displays, etc. Integrated avionics was a major technological advance, and proved to be one of the most challenging. There are plans to extend the 777 product family shortly. A stretch version (242 feet, 4 inches) with an added fuselage section will be available soon. An extended range version (7,000 miles versus 4,000 miles) will be available in December 1996.

One of the major goals was to develop the plane in 50% less time than the 767. The only way to do this was to reduce engineering changes and rework significantly. That required abandoning the traditional sequential design process. This was accomplished by introducing "The Preferred Process" which involved concurrent engineering among co-located cross-functional representatives in design-build teams (DBTs). There were 250 DBTs, each having approximately 15 members including representatives from finance, and customer service. Concurrent product and process definition occurred within DBTs prior to design release. This is particularly challenging when customers often want to make late changes. Major suppliers and customers were members of various DBTs. The focus was on design and integration of structures, systems, manufacturing plans and tool designs concurrently. DBTs were to try to reach agreement among themselves, with unresolved differences settled by a higher level integration team. All core and support members of DBTs received training in team facilitation and team dynamics.

Another innovation was 100% CATIA digital product definition. CATIA was the sole authority on the design of parts, which are displayed as 3D solids. The system could raise red flags about potential integration problems, and provide updates and status reports to team members. Also, parts were color-coded so that DBTs could more easily identify potential interferences between parts. CATIA also allowed the use of digital preassembly whereby tests of interference and alignment among parts could be evaluated before parts such as tubes, wires, and insulation blankets were assembled. CATIA also helped to design sufficient space for mechanics to extract parts that needed to be repaired, which is an important dispatch reliability issue. The plane was designed with flexi-zones which permitted wide discretion regarding what was designed within them. For example, customers could select from forty-two

varieties of lavatories, each of which could fit within a flexi-zone. The interior of the plane is very customer driven.

The 777 project was developed at a greenfield site with virtually complete dedication of resources for the project. Boeing primarily does the final assembly of the plane with a significant amount of the plane's parts outsourced to domestic and international suppliers. Suppliers vary in their contribution to the design. Some suppliers are given a virtual black box concept and allowed to design the product themselves. Other suppliers simply build what Boeing has designed for them. Boeing does not outsource the cockpit and nose of the plane nor the wings. The technologies in these sections are proprietary. The final assembly went extremely well with alignments within thousands of an inch.

Product Development Team Effectiveness Study: Findings and Managerial Implications

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This study suggests that practices related to team leadership and performance evaluation and rewards affect project performance differently in high or low risk projects. In particular, a strong product-based focus is best for low risk projects, while a balance between a product-based and function-based focus is best for high risk projects. An earlier study at MIT, the International Motor Vehicle Study, suggested that product-based organizations have more effective product development teams than do function-based organizations. However, the product development projects studied by MIT were derivatives from a base platform, or low risk projects.

A model has been developed that predicts that effective project outcomes depend on structural integrative mechanisms (SIMs), e.g., dedicated assignments, co-location of team members, time spent upstream by downstream personnel, and time spent downstream by upstream personnel. They depend also on process integrative mechanisms (PIMs), e.g., program manager versus function manager influence, and rewards based on team performance. Effective project outcomes also depend on group processes (GPs), e.g., team participation in decision-making, satisfaction with inputs into the design process, and an integrative problem-solving style. They also depend on codified and computerized (CCs) manufacturing data and design rules. These latter two categories were not highlighted in this presentation. PIMs were highlighted. Low risk projects perform best when program managers have more influence than function managers and rewards are team-based. High risk projects perform best when there is a 50/50 balance on these PIM attributes.

Data were collected by survey and telephone interviews from thirty-two projects from companies that attended Penn State's Advanced Manufacturing Program, and from twenty-three projects from companies that participated in the Lean Aircraft Initiative at MIT. The Penn State sample consisted of ten projects from a photographic equipment company, ten projects from an earth moving company, and five projects from a U.S. Army Depot. The MIT sample consisted of one or two projects from ten aircraft and aerospace companies or from three Air Force Centers. The Penn State sample consisted

four low risk projects. Projects were categorized as high risk if the answer was yes to two of the following three questions: (1) Was the project new to the company or new to the world?; (2) Does the product incorporate any new product technologies?; and (3) Was the product manufactured using any new process technologies?

Project outcomes were measured by asking team leaders to provide percentages achieved on five project goals (seven for MIT): development cost, unit cost, product performance, quality, and schedule (MIT broke quality into product and process, and added life cycle costs). The percentage achieved for each target was weighted by asking team leaders to distribute 100 points between the five or seven goals. For the Penn State sample, this measure was validated by data provided by superiors that were one to two levels removed from the team leaders. They were asked to assign a number from 1 to 10 and to rank order the projects in their respective companies on a global measure of effectiveness (rather than on the five goals used by team leaders). The correlations between the outcome scores derived from team leaders and those of their superiors were .42 ($p < .01$) for the 1-10 score and .35 ($p < .05$) for the rank order.

Preliminary analysis showed that high and low risk projects differed initially on several dimensions, which may help explain why such projects react differently to project leadership and rewards. For example, team leaders of high and low risk projects prioritize project goals differently. In the Penn State sample, team leaders of high risk projects ranked performance goals highest and unit costs second to lowest (development costs were ranked the lowest), while low risk projects rank unit costs highest and performance goals were second to lowest (again, development costs were lowest). The MIT sample, consisting mainly of high risk projects, had rankings similar to the high risk projects in the Penn State sample. Also, team members in both samples were asked to judge how much weight they thought that team leaders gave to these goals when assessing team member performance. Schedule and performance were weighted the highest in the high risk projects in the Penn State and MIT samples (unit cost was second from lowest). Schedule, performance and unit costs were weighted about equally in the Penn State sample of low risk projects. Finally, data from the MIT sample suggested that time spent by downstream team members in upstream phases, e.g., in concept development, was related to project effectiveness.

An index was developed for the Penn State and MIT samples that was based on the number of individual items that were characterized as PIMs. If a team scored above the median for the entire sample on an item, they were given a score of 1. If the team scored below the median, the score was 0. Since the maximum number of PIM items was three in both the Penn State and MIT samples, the PIM index could vary between 0 and 3. As expected, the results showed that the PIM indices have a more positive effect on low risk projects than on high risk projects in the Penn State sample. In the Penn State high risk sample and in the MIT sample, PIMs even showed a slightly negative effect on project outcomes. Comparisons between pairs of projects with the highest and lowest outcomes supported this result. A follow-up study is underway to understand better how balance between a product-based and function-based focus really works in the most effective high risk teams.

Human Resource Policies and Practices That Facilitate New Product Development Success

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Caterpillar was formed from two smaller agricultural vehicle companies, Holt and Best, in 1925. The new company expanded into vehicles for road building and infrastructure. Caterpillar now has thirty-two plants world-wide and employed 50,000 people. There are 183 dealerships, which employ another 50,000 people. It manufactures 300 different products, which contain from 60 HP to 1000 HP diesels. A decision was made in 1985 to expand into the small machine business, which Case, Deere and Ford dominated. The customers for these products, "backhoe loaders," are very different from Caterpillar's typical large customer. The customers for small machine products are usually small contractors.

The Building Construction Products Division was function-based initially, but has been evolving toward a product-based structure. The New Product Introduction (NPI) Team oversees major development and product maintenance activities for the Division. The NPI process includes commitment to customer responsiveness, with frequent product updates and limited risk by modifying product generations gradually. It encourages cultural change toward being proactive, team-oriented and accountable. The NPI Team encourages decision-making to move from the functions to the teams. The team members received some training in team operations and decision-making from facilitators. The teams are expected to meet cost, reliability, schedule, functional specifications, process conformance, manufacturability, etc.

At the end of each calendar year, the functional managers assess their functional representatives on the team as individuals and the team is assessed as a whole. The functional managers are encouraged to seek the opinions of other functional managers. Individual attributes include technical skill and teamwork. Team attributes include meeting cost, reliability, schedule, etc. Merit-based pay is dependent on the outcome of such assessments, and contributes to the base for future salary increases. Additionally, a one-time increment may be added based on profitability, percent of industry sales, and customer satisfaction.

The Backhoe Loader (BHL) product development team actually consists of an overlapping "System Team" and "Commodity Team." The U.S.-based Commodity Team primarily has technical responsibilities and includes engineering, vehicle and component testing, analysis, marketing, and product support. The Engineering representative is also a member of the Commodity Team, which has commercial responsibilities. It is based at an assembly facility in Leicester, England and includes quality, purchasing, accounting, and suppliers who fabricate virtually all components. Most members of the System Team are committed nearly full-time. Many members of the Commodity Team had to devote part of their time to other projects. Communication between these two teams occurred consistently about every two weeks. They held face-to-face meetings about every two months. A set of separate and joint roles and responsibilities was developed in advance for each team.

Members of both teams participated in the Concept Phase. They used Quality Function Deployment to get a clear concept of the overall vehicle and its position relative to competitors' products. The Marketing representative collected data on customer perceptions of Caterpillar's products, which typically

were viewed as more expensive than those of competitors. Functional and technical specifications, concept layouts, and target costs were set. The advanced process and assembly plans in Leicester included a switch from assembly lines to stalls. Suppliers were selected during the Concept Phase also. Detailed product and process design was carried out simultaneously by video conferences and frequent exchange of files between the U.S. and Leicester. The team learned that design for manufacturability (DFM) guidelines need to be balanced against the costs of more complex parts. Four prototype vehicles were developed for testing with customers of Caterpillar's competitors in four different geographical regions of the country.

Process reliability has been high after a slower-than-expected start, and has prompted greater attention in future projects to validating supplier processes. The backhoe loader was produced in less time, with lower target costs, research and development costs, and capital outlays than anticipated. Profitability has been about double expectations. North American market share has jumped from 12% of industry sales to 25%.