A System Architecture Approach to Global Product Development

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Working Paper Number 4645-07
March 2007

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Acknowledgments:

This research project has been funded by a grant from Parametric Technology Corporation. The authors are grateful for the cooperation of representatives from the five case study companies who gave generously of their time and insights about the structure and management of global product development. In addition, MIT LFM student Sabrina Chang and MIT SDM student Cheolmin Park contributed substantially to two of the cases.

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Abstract

Recent advances in engineering collaboration tools and internet technology have enabled the distribution of product development tasks to offshore sites and global outsourcing partners while still maintaining a tightly connected process. Most firms in complex engineering industries are indeed experimenting with various ways to structure their product development processes on a global basis. In this research, we have explored global product development structures from the perspectives of process flow and system architecture. We employ the design structure matrix method to display and explain these structures and our observations thereof. Through five case studies spanning electronics, equipment, and aerospace industries, we consider the interaction complexity inherent in various global work distribution strategies. We conclude the paper with a summary and directions for future research work.

Introduction

Of late the subject of global product development has generated a lot of interest. Competitive pressures (pricing targets driving aggressive cost targets), availability of exceptional talent overseas, availability of communication media for seamless information flow, availability of intellectual property protection, and growing external markets, are some of the factors which are influencing the drive towards global product development (GPD). At the same time, there has been a lot of concern raised on where to do GPD, and more importantly, how to do GPD. This paper studies the approach followed, using system architecture principles and utilizing the design structure matrix (DSM) tool, by five companies in engineering and high-technology industries.

This paper first provides a brief survey of existing literature on global R&D. We then discuss systems architecture and how architectures can be decomposed using DSM to identify patterns for outsourcing/offshoring. We then present five case studies followed by a discussion on potential future research in this area.

Though there has been past work in the area of global research (global R&D), the stress has primarily been on research or turnkey development. Collaborative development, whereby different processes or components of the product are developed in dispersed parts of the world, has not been yet researched in depth. Eppinger and Chitkara (2006) defined global product development as combining certain centralized functions with some engineering and related PD functions distributed to other sites or regions of the world – the practice may involve outsourced engineering work along with captive offshore engineering facilities. They define benefits of GPD to include greater engineering efficiency (through utilization of lower cost resources), access to technical expertise that is distributed internationally, design of products for more global markets and more flexible PD resource allocation (through use of outsourced staff).

Academic literature is rich in the study of global R&D, virtual teams, distributed development, etc. Kuemmerle (1997) differentiated global R&D sites between those that are home-base augmenting and those that are home-base exploiting. The home-base augmenting R&D sites absorb knowledge from the global scientific community, create new knowledge, and transfer it to the company's central R&D site. In contrast, home-base exploiting R&D sites commercialize knowledge by transferring it from the company's home base to the laboratory site abroad and from there to local manufacturing and marketing. Gassmann and von Zedtwitz (2002), while agreeing on the above two reasons for global R&D sites, defined four archetypes of R&D internationalization –

a) national treasure, where both research and development are done domestically
b) technology-driven, where development is domestic and research dispersed
c) market-driven, where research is domestic and development dispersed
d) global R&D, where both research and development are dispersed

Companies would normally start from a) and then proceed, either through b) or c) above, to d) global R&D. In contrast, Chiesa (2000) defined foreign-based R&D laboratories based on two structures – specialization based (where the laboratory has full global responsibility for a product or technology or process) and integration based (where different units contribute to technology development programs). These integrated R&D laboratories with their networks do get involved in GPD in terms of the definition provided by Eppinger and Chitkara (2006).

Beyond defining global R&D and GPD, it is imperative to understand why these efforts are undertaken, how these efforts are undertaken, and the challenges and issues faced in these efforts. Some of the reasons for proceeding on global R&D and GPD have been identified in an earlier part of this paper. As Eppinger and Chitkara (2006) pointed out, GPD is gaining prominence for many reasons, chief among which are leveraging lower costs, improved processes available on account of focus on design for manufacturing (1980s) and time to market (1990s) earlier, global growth in markets requiring instant access to market, and availability of integrated PD processes (leveraging on advances in digital and networked technology) that include engineers in regions where critical new technology has been developed.

Coupled with the why is the where to do GPD question. Kumar (2001) studied the determinants of location of overseas R&D in multinational enterprises of US and Japanese origin and found that the key factors favoring location of overseas R&D were large domestic market, abundance of low-cost R&D manpower, and scale of national technological effort. A significant proportion of the studied firm's R&D activities followed that of leaders in their own fields. Further, lack of patent protection or restrictive trade regime does not affect the attractiveness of a country which is otherwise suited for R&D expansion. However, he also noticed that Japanese firms' R&D abroad was more in low-tech products. Through their study of Japanese, European and US based multinational enterprises, Bas and Sierra (2002) found that companies decided on investing in R&D after comparing relative advantages of home and host countries. The key strategies followed fall into four broad types –

- technology seeking, where the company tries to offset home country weakness in a given technological field by selecting a host country with proven strength in the technology
- home base exploiting, where the technology is created at home but then adapted in the foreign location to exploit the market
- home base augmenting, where the technology base is strong in the company at home and at the host and the idea is to acquire knowledge from the host
- market driven, where the technology base is weak both at home and at host

Julian and Keller (1991) listed a number of factors that contribute to the identification of R&D locations. Besides factors mentioned above, they also identified national market importance, local considerations like government incentives, and modes for implementation (greenfield, joint-venture, foreign acquisition, global matrix structure) as influencing factors.

The key issues that academic literature have tried to address with respect with global R&D are how to manage the R&D sites and issues regarding culture/teams/communication. Hakonson and Zander (1988) studied the internationalization of R&D efforts of four Swedish companies and concluded that a strategic balance is required in managing the R&D sites. Corporate R&D needs to carry out the central task of acting as liaison between the R&D organization/sites with corporate management (to ensure conformance of R&D to corporate objectives), facilitate communication within the group, develop common standards, etc. Detailed R&D needs to be conducted and tracked by divisional R&D departments, who will coordinate worldwide efforts of the products. The line responsibility should lie with individual country/market leads. Graber (1996) in his discussions on global R&D efforts of Black & Decker's Worldwide Household Division, identified the global business team structure as a very important ingredient to GPD, along with top management commitment. Julian and Keller (1991) have added that coordination and control and steps to prevent leakage of information, and managing the government policies and political risks, are critical to success of global R&D efforts. Pearch and Papanastassiou (1996) have stressed the need for adequate networking to enable global R&D success. Asakawa (2001) discussed managing the organizational tensions prevalent in global R&D. He has used perception gap as a primary manifestation of organizational tension within a firm and claims that this gap occurs due to two main reasons – information sharing issues and autonomy related issues. Formation of overseas R&D labs go through a process starting as a starter, going on to become an innovator through a process of disintegration wherein autonomy is passed onto the local unit and the local unit feels that there is not sufficient information-sharing by the parent, and finally becomes a contributor through a process of re-integration wherein autonomy related tension rises.

The other big challenge with global R&D and hence with GPD is with the global teams – how will they operate, will they be able to work together, what will be the methods/modes of communication and information sharing. de Brentani and Kleinschmidt (2004) identified four scenarios for international product development – positive balanced, hands-off approach, no budget for international PD and high involvement only. They suggested that the scenario followed played an important contributory role towards the success of international PD efforts. The best performers needed to be positive balanced, needed a strong innovation-plus-globalization culture for PD, solid top-management involvement, and sufficient resources to support the program. Kahn and McDonough (1996) identified that the biggest problems faced with global teams are social and cultural – communication, interpretation, promoting trust, getting over the not-invented-here syndrome. Similarly, Barczak and McDonough (2003) believed that the key challenges for a global NPD team leader were both interpersonal (trust) and programming (program milestones, tracking, responsibilities, resources). They advise that the global NPD teams should meet initially for at least 3 days, to increase the amount and quality of communication, and hold periodic progress meetings. Cedrone and McDonough (2000) suggest that individuals have a strong desire to perform well in the eyes of other members of the network of peers and it may be advisable to allow them to choose their tasks/work through which they may want to contribute. Managing communications is a crucial task of the team leader. Cummings (2004) has found that virtual teams can be effective without ever meeting in person.

Yet another branch of literature deals with knowledge transfer in global R&D networks. In particular, tacit knowledge has been studied, which is difficult to measure or monitor for transfer. Subramaniam, Rosenthal, and Hatten (1998) observed that European and US based multi-national enterprises seemed to employ cross-national PD teams and use overseas subsidiaries as sources of new product concepts when knowledge about different product design requirements among overseas markets or plants is tacit. Subramaniam and Venkatraman (2001) studied NPD capability and tacit overseas knowledge, and concluded that companies that harness greater tacit insights about overseas markets are more likely to have greater transnational NPD capabilities. Tacit knowledge `indwells' in minds of people of an organization, and the inherent difficulties in its codification and communication pose significant barriers to the replication of the same by rival organizations, and hence it is an important strategic resource. Subramaniam (2006) concluded that instead of cross-national teams or cross-national communication, cross-national collaboration (involving effective transfer of embedded knowledge) enhances the embodiment of embedded knowledge into the product.

Though most of the global R&D or GPD studies have reflected on why they should be done, the challenges faced therein, etc., they have not addressed the key issue of how it should be done. In particular, they have assumed that it is possible to transfer the complete responsibility of the product or the process to a global site. Such an assumption may not hold in the case of complex products which are developed by teams whose strength may be in hundreds or thousands. In such cases, a stage based approach may be necessary. We suggest in this paper that system architecture could be used as a tool to identify the approach towards GPD.

System Architecture

A complex engineering product generally comprises of a large number of components. In such a case, a hierarchy can be established wherein the product or system is decomposed into sub-systems, and those sub-systems further decomposed into components. There could be more than a single level of sub-system decomposition before arriving at the component level. In such an environment, the system is defined as a set of different elements so connected or related as to perform a unique function not performable by the elements alone (Rechtin and Maier (1997)). The sub-systems within the system and the components within a sub-system are interconnected or dependent on each other and these relationships define the system architecture. Complexity of a system is defined by the complexity of the interconnections and/or the dependencies in the system architecture. Architecture therefore relates to the structure – in terms of components, connections, and constraints - of a product, system, process, or element. Architecting is the process of creating and building architectures, mostly those aspects of system development most concerned with conceptualization, objective definition, and certification for use. Rechtin and Maier (1997) define system architecting as the art and science of creating and building complex systems, the part of systems development most concerned with scoping, structuring, and certification. System architecting can be of two types – the art which is based on qualitative heuristic principles and techniques, and the science which is based on quantitative analytic techniques.

The architecture of a system can be looked at in many ways – product architecture, process architecture, organizational architecture, etc. Ulrich (1995) defined product architecture as the scheme by which the function of a product is allocated to physical components, driving the performance of the product, product variety, product change, etc. Gulati and Eppinger (1996) have shown that an intricate relationship exists between product architecture and organizational design, each relying upon and driving the other. Henderson and Clark (1990), through their study of the photolithographic industry, have shown that product architecture is embedded in the information flow system of the firm and any change in the architecture has the potential to destroy the firm. In a similar way, process architecture can be defined as the set of tasks and the related information flow between them, that sum to produce the final product/system. Organizational architecture can be defined as the small sub-teams in a project involving the development of a system/product and the relationships, in terms of information flow, hierarchy, etc., existing between these sub-teams.

In a complex system (product), it is often impossible to study, design, or source, the entire system. Hence it could be necessary to decompose the system. Often such decomposition is necessary to identify the cause of a problem, or to identify a level of sub-system/component that can be designed or outsourced, or a level at which a sub-team can be assigned responsibility. von Hippel (1990) has proposed that firms specify tasks in order to reduce the problem-solving interdependence amongst them by predicting which tasks are likely to be important new information sources and which tasks affect each other.

Design structure matrix (DSM) can be a useful tool to decompose the architecture of a system, either by product or by process or by team or as a hybrid of these. The DSM is a project modeling tool which represents the relationships between project tasks or sub-systems/components in a matrix form. It was first proposed by Steward (1981). Eppinger, Whitney, Smith and Gebala (1994) defined the use of DSM in organizing tasks in product development. DSM helps to first decompose the system (by product, process or as required) and then identify the relationships or information flow, if any, between these decomposed sub-systems, tasks, sub-teams. Under ideal circumstances any/all relationships or information flow should be on the same side of the diagonal of the matrix (or it should be possible to obtain that structure). If that is not true, then it represents a case of feedback loop (in case of process decomposition) or a case for concurrent engineering (product decomposition). In case of organizational decomposition, it could represent a case of requiring the teams to be co-located. At times, it may be possible to `tear' off a dependency to enable a desired decomposition. However, such an effort requires inputs from very experienced people. An extension of the DSM is the numerical DSM where numbers, either absolute or relative, are input into the matrix and help in making decisions.

GPD and System Architecture

As outlined earlier, there is no academic literature outlining the steps or methods for a company to engage in GPD. System architecture, using the DSM methodology, appears to provide an approach to address the same. Decomposition of the architecture, by product, process, or both, could be used to identify sub-systems or components or tasks that could be taken up for GPD.

In this research, we explore the GPD efforts of five companies. We study how each of these companies initiated and progressed their GPD efforts, and what motivated these steps. The companies studied are involved in the development of either complex or high technology products. We have tried to analyze the GPD efforts of each company through a system-architecture approach. Using the existing theories and tools of system architecture, we have attempted to study how each of these companies decomposes either processes or products to initiate, and subsequently further, their GPD efforts. We have tried to understand the rationale for selection of the type of decomposition and subsequently, the particular process/component/sub-system chosen to initiate GPD. For companies following a process-based GPD approach, we try to understand their task structure, the information flows between different processes, and how this process based architecture influences their GPD efforts. Similarly, for companies that have used product decomposition, we have tried to understand how the product has been decomposed to systems, sub-systems and parts, the existing interdependencies between the systems/sub-systems/parts so defined, and how the same has motivated their GPD approach. Finally, we came across a company that was in the process of setting up a new department and was looking at exploiting the labor cost differences to staff the department. In such a case, the use of task decomposition to sub-tasks and identification of co-ordination requirements between sub-tasks play a major role in identifying the tasks that can be located offshore. The task definition for offshoring and the ability to get the task done offshore can be a very challenging proposition (a parallel can be drawn to Fine and Whitney (1996) who have said that the ability to develop and realize the engineering specifications for an outsourced component is a core competence). In the course of our study, we have encountered questions and thoughts regarding the respective approaches followed, whether the approaches were optimal, could something different have been done, what could be the next GPD step/challenge that the companies could have faced, etc. While system architecture, in some form, either willfully or unknown, has been used by the companies, we were also interested in finding if there was a single approach or over-arching framework, based on system architecture, that could explain the GPD approach of these companies. We were also interested in knowing the communication challenges and process difficulties faced during GPD.

Our study showed that GPD efforts tend to differ by company, and perhaps we may extend it to say that they also differ by industry/product that the company is involved in. Danaher Motion started GPD through process/task outsourcing, though the medium- to long-term plan would see them move to a product (functional) architecture based GPD approach with the outsourced and offshored GDC (Global Development Center). Pitney Bowes' product architecture allows them to follow GPD with sub-systems clearly segregated with well defined interfaces once the system architecture is developed. Intel follows a equi-competency model wherein each of their development centers is capable of developing the chips, by components and by task, though individual development centers have their respective specializations. So, the Intel approach, wherein a team meets first and works on a central location during architecture and floorplan definition, then disperse to their respective home locations and come together again for unit integration, requires a hybrid (product cum process) decomposition, which is captured by the DSM. Cessna uses a product based decomposition to identify components and module for GPD development at their offshore Global Technology Center (GTC) – where they actually use a hybrid model of outsourcing tasks where capability is available at the host country, but insource tasks/sub-system development that are either specialized or part of their core competency. Honeywell, on the other hand, was on the verge of starting a new department and a modeling approach (using a combination of process-DSM followed by math programming) was suggested to help them differentiate the tasks between on-shore, near-shore and off-shore. We present details of each of the above case studies, and follow up with certain future research avenues that can be explored.

Case Study 1. Danaher Motion, Precision Systems Group: Task Outsourcing

The Company

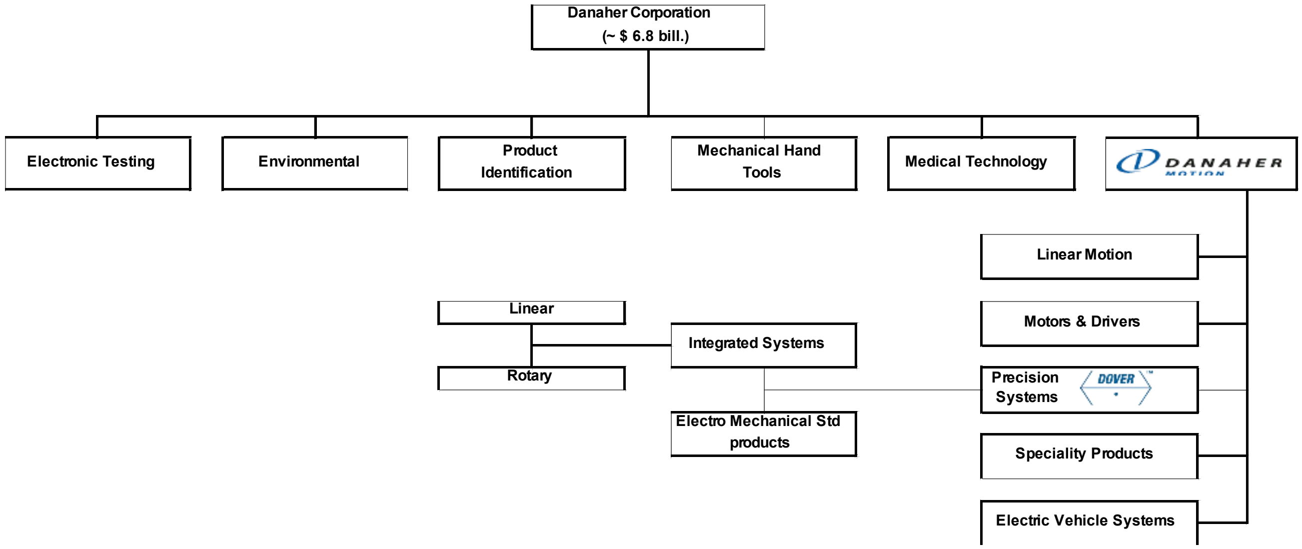
Danaher Corporation is a leading US-based manufacturer with FY 2004 revenues of $6.8 billion and a worldwide workforce of approximately 37,000. Danaher's business activities encompass six strategic platforms: environmental, medical technology, electronic testing, motion, product identification, and mechanic's hand tools. (See **Figure 1.1**)

Danaher Motion, a business unit of Danaher, provides solutions for a wide array of product areas including robotics, wheelchairs, lift trucks, electric vehicles, and packaging machines. These solutions are characterized by their flexibility, precision, efficiency, and reliability.

Dover, a unit of Danaher Motion, is part of the Precision Systems group of Danaher Motion. Dover's core technology, air-bearing-based precision motion (linear and rotary), can be found in high performance machinery utilized in a wide array of industries including data storage, flat panel display, semiconductor lithography and wafer inspection, circuit board assembly, high precision assembly, and metrology. Dover's 75,000 Sq. Ft. engineering and manufacturing facility is located in Westborough, MA.

Due to its ability to develop customized solutions based on its core technology, Dover has a loyal customer base which values the quality, speed and agility with which their needs are addressed. In a typical scenario, Dover's order to delivery timeline is just six months.

Figure 1.1 Danaher Corporation Organization Structure



The Product

While Dover largely focuses on providing customized solutions, the architecture of its products can be broadly described as follows:

Structure contains the core air-bearing technology. It is primarily made up of the frame/weldment structure (support), the isolation system (prevents vibration from the floor), the granite platform, and the motion.

Control System has all the electrical parts that are used in the product including power systems, utilities, hydraulics, pneumatics, amplifiers, and computers.

Software implements the unique requirements of every product, including interface with users and related equipment.

With the exception of some of the basic structural components and final assembly, the majority of Dover's components are purchased from a network of internal and external suppliers. As part of the Danaher Corporation, Dover has an added advantage of being able to internally source many such industrial parts from some of the 70 companies that make up the Danaher corporation.

Product Development

Dover's quick order-to-delivery timeline requires quick engineering turnaround. Quick turnaround involves large groups of engineers working together to provide solution alternatives and rapid design iterations as well as concurrent design, engineering, and manufacturing process development. Many component designs are translated into production parts with no prototype production. The combined requirements of quick turnaround and customized products present a challenging proposition to Dover's engineering staff whose experience has helped them to address these challenges.

Product development at Dover follows a six-stage process, each of which concludes with a tollgate:

Stage 1: Agree to specifications and deliverables with customer, ensure commercial viability, and obtain purchase order from customer.
Stage 2: Brainstorm ideas leading to concept freeze and customer approval.
Stage 3: Design review, accept system design and design freeze, develop bill of materials, release design for procurement and manufacturing.
Stage 4: Develop manufacturing plan including integration planning, engineering release, FMEA analysis, manufacturing evaluation.
Stage 5: Check and ensure quality control; ship product.
Stage 6: Review the entire program (what worked/what didn't, lessons learned) 90 days after shipment of first product.

A toll gate's duration varies by product and customer need.

Global Product Development

GPD is a corporate-wide initiative at Danaher Motion. Danaher Motion identifies global outsourcing agencies and directs group companies to use them. Thus far, GPD at Dover has evolved through two of three planned GPD phases:

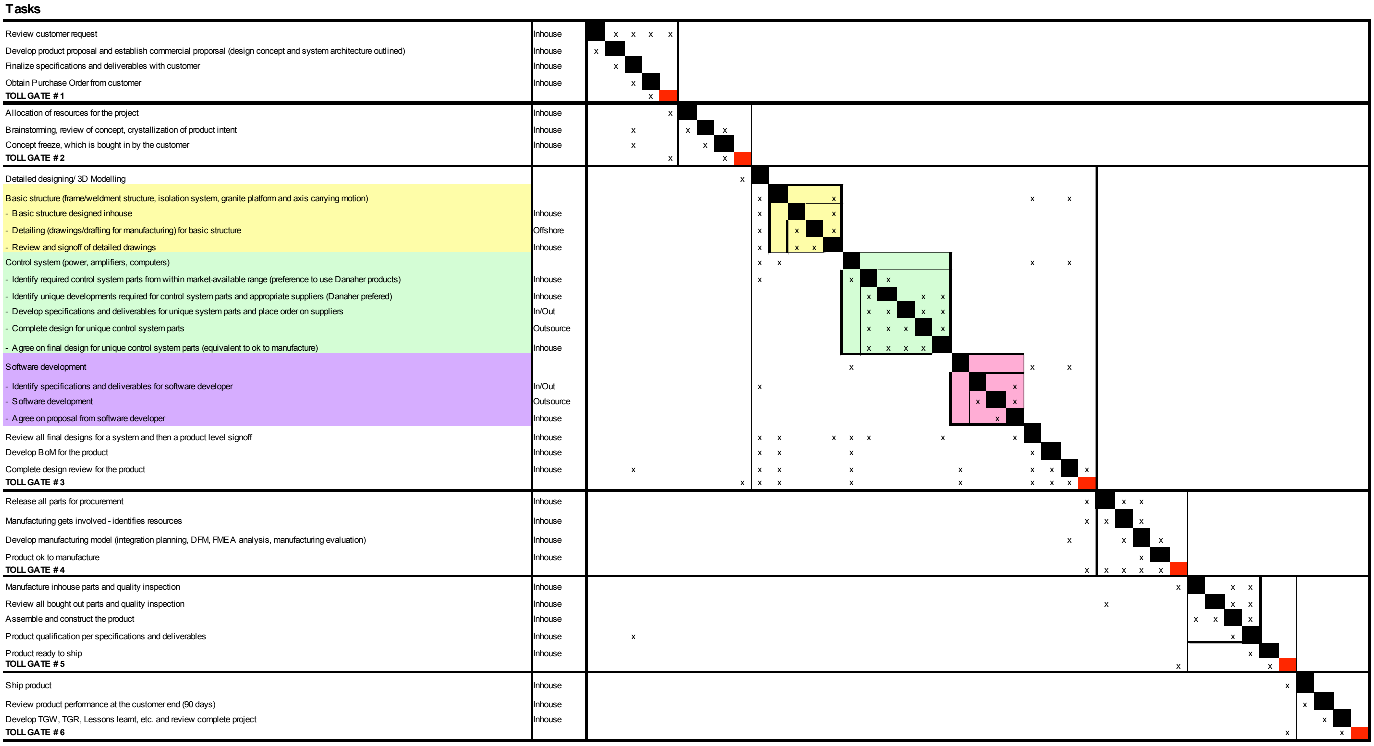
Phase 1: Learning about Outsourced Engineering

As a first GPD effort, Danaher Motion began requiring that its businesses use a specific engineering service provider based in India for outsourcing certain process-driven engineering jobs such drawing, detailing for manufacturing, CAD, etc. As shown by the DSM in **Figure 1.2**, these processes were separated from the others to enable them to be outsourced. The DSM lists the tasks by the stage. The column next to the task outlines the location where the task is performed (Phase 1). While most tasks were performed inhouse, some followed a mix of inhouse and outsource (shown as in/out in Figure 2), some were totally outsourced, and detailing (drawings, drafting) of basic structure was outsourced to the offshore service provider. The outsourced engineering service firm found the quick engineering turnaround requirements of Dover's business very challenging.

Phase 2: Setup of Global Development Centre (GDC)

In time, Danaher Motion began embarking on a larger outsourcing plan. It began requiring that all group companies outsource to a different, much larger engineering company in India, which offers a wide range of engineering services and solutions. As a beginning step Dover outsourced tasks of the same complexity level as had been outsourced in Phase 1 as a way to directly compare the two companies' performance.

Figure 1.2 Danaher Motion Process-based DSM

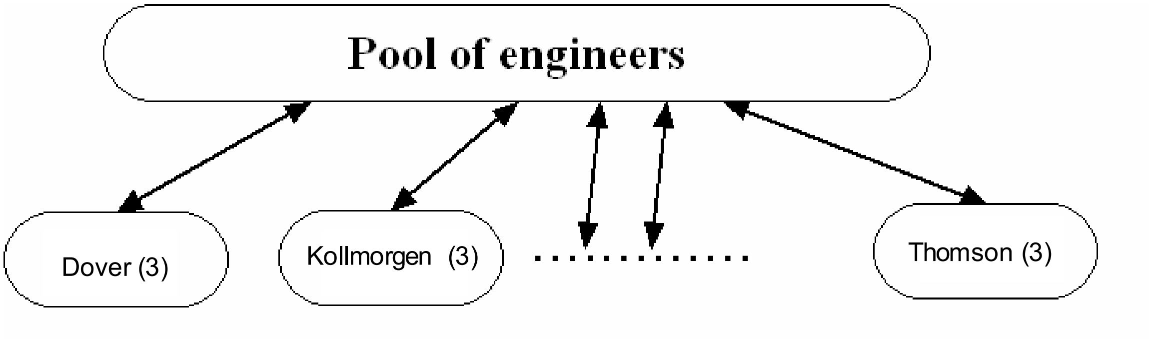


Tasks	
Review customer request	Inhouse
Develop product proposal and establish commercial proporsal (design concept and system architecture outlined)	Inhouse
Finalize specifications and deliverables with customer	Inhouse
Obtain Purchase Order from customer	Inhouse
TOLL GATE # 1	
Allocation of resources for the project	Inhouse
Brainstorming, review of concept, crystallization of product intent	Inhouse
Concept freeze, which is bought in by the customer	Inhouse
TOLL GATE # 2	
Detailed designing/ 3D Modelling	
Basic structure (frame/weldment structure, isolation system, granite platform and axis carrying motion)	
- Basic structure designed inhouse	Inhouse
- Detailing (drawings/drafting for manufacturing) for basic structure	Offshore
- Review and signoff of detailed drawings	Inhouse
Control system (power, amplifiers, computers)	
- Identify required control system parts from within market-available range (preference to use Danaher products)	Inhouse
- Identify unique developments required for control system parts and appropriate suppliers (Danaher prefered)	Inhouse
- Develop specifications and deliverables for unique system parts and place order on suppliers	In/Out
- Complete design for unique control system parts	Outsource
- Agree on final design for unique control system parts (equivalent to ok to manufacture)	Inhouse
Software development	
- Identify specifications and deliverables for software developer	In/Out
- Software development	Outsource
- Agree on proposal from software developer	Inhouse
Review all final designs for a system and then a product level signoff	Inhouse
Develop BoM for the product	Inhouse
Complete design review for the product	Inhouse
TOLL GATE # 3	
Release all parts for procurement	Inhouse
Manufacturing gets involved - identifies resources	Inhouse
Develop manufacturing model (integration planning, DFM, FMEA analysis, manufacturing evaluation)	Inhouse
Product ok to manufacture	Inhouse
TOLL GATE # 4	
Manufacture inhouse parts and quality inspection	Inhouse
Review all bought out parts and quality inspection	Inhouse
Assemble and construct the product	Inhouse
Product qualification per specifications and deliverables	Inhouse
Product ready to ship	Inhouse
TOLL GATE # 5	
Ship product	Inhouse
Review product performance at the customer end (90 days)	Inhouse
Develop TGW, TGR, Lessons learnt, etc. and review complete project	Inhouse
TOLL GATE # 6	

Phase 2 also included the creation of an outsourced Global Development Centre (GDC) in India, which would be staffed with up to 125 engineers over a period of three years. Productivity gain was identified as one of the GDC's key benefits, with growth of design and development throughput of 30% over three years at existing budgets.

A key part of the GDC's strategy has been the utilization of a flexible workforce, whereby GDC engineers are part of a pooled resource and work on projects on an as-needed basis (**Figure 1.3**). Each Danaher Motion company (e.g., Dover, Kollmorgen, Thomson) has dedicated project engineers in the GDC who are responsible for utilizing the pool of engineers. These project engineers are trained at respective Danaher Motion companies and provide specific product-related expertise. In contrast, the engineers which belong to the pool provide the specific engineering skills based on job requirements. Over time, Danaher Motion expects the GDC to take up greater sub-system/component responsibility.

Figure 1.3 GDC Flexible Workforce

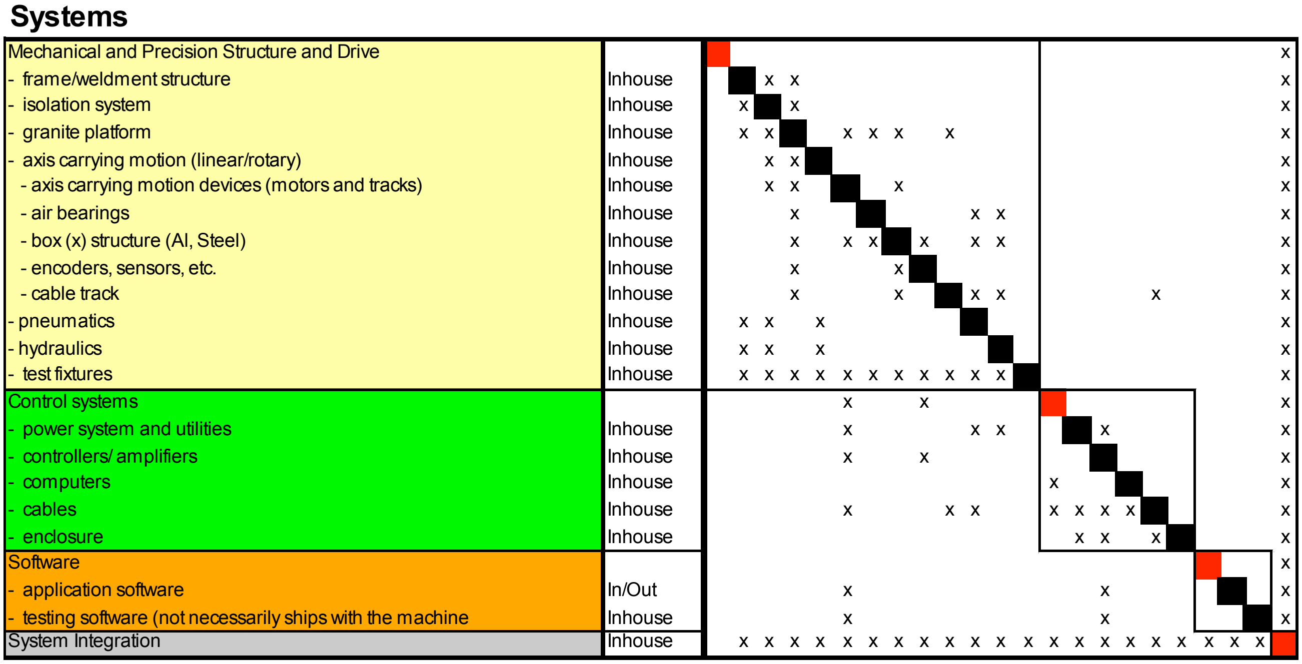


To implement this strategy, three engineers were hired to be dedicated Dover project engineers based at the GDC where they received mechanical engineering training. In addition, they received training on Dover's structured and documented processes to enable a seamless transfer of responsibility to the GDC in the future, assuming the model proved successful. Electrical engineering, an important area with a lot of potential for outsourced development, has not been considered yet as the documentation is still under development.

Phase 3: Increasing Utilization to Achieve Efficiency and Scale

The next phase for Dover's GPD efforts (and Danaher Motion's) could include a higher level of involvement by the GDC in future product development. Once the project engineers go back to the GDC after being trained, they will be given specific assignments and design tasks and their performance will be reviewed. The next stage, subject to satisfactory progress, could involve the transfer of complete component or sub-system design responsibility. From the Architecture-based DSM, the control system parts have limited information feedback to other systems/parts (**Figure 1.4**). Additionally, most of the systems/parts tend to confirm to or adapt from industry standards. Hence once the specifications of the electrical/control parts are complete, their development can be moved off-shore. An added advantage that electrical/control parts have is that they normally tend to follow industry standards. Therefore, identifying expertise may not be difficult. It is imperative, therefore, that Dover develop the required processes and documentation for these parts.

Figure 1.4 Architecture-based DSM



Systems

Mechanical and Precision Structure and Drive		🟥																						x
- frame/weldment structure	Inhouse		■	x	x																			x
- isolation system	Inhouse		x	■	x																			x
- granite platform	Inhouse		x	x	■		x	x	x		x													x
- axis carrying motion (linear/rotary)	Inhouse			x	x	■																		x
- axis carrying motion devices (motors and tracks)	Inhouse			x	x		■		x															x
- air bearings	Inhouse				x			■				x	x											x
- box (x) structure (Al, Steel)	Inhouse				x		x	x	■	x		x	x											x
- encoders, sensors, etc.	Inhouse				x				x	■														x
- cable track	Inhouse				x				x		■	x	x						x					x
- pneumatics	Inhouse		x	x		x						■												x
- hydraulics	Inhouse		x	x		x							■											x
- test fixtures	Inhouse		x	x	x	x	x	x	x	x	x	x	x	■										x
Control systems							x			x					🟥									x
- power system and utilities	Inhouse						x					x	x			■	x							x
- controllers/ amplifiers	Inhouse						x			x							■							x
- computers	Inhouse														x			■						x
- cables	Inhouse						x				x	x			x	x	x	x	■					x
- enclosure	Inhouse															x	x		x	■				x
Software																					🟥			x
- application software	In/Out						x										x					■		x
- testing software (not necessarily ships with the machine	Inhouse						x										x						■	x
System Integration	Inhouse		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	🟥

Pneumatics and hydraulics of the basic structure are also potential design outsource candidates. However, the design of axis carrying motion components, a core technology that needs extensive on-site collaboration, needs to stay in-house. Also, being a core technology, Dover would want to protect this intellectual property. However, the other mechanical parts (frame/weldment structure, isolation system and granite platform), though they have dependencies (both from and to them), could be outsourced. Some strong lines of communication have to be developed to ensure smooth development.

Beyond the transfer of component/sub-system design responsibility, it is imperative that Dover utilize the GDC's engineering capabilities. The engineering firm running the GDC is renowned in India for its engineering prowess. If given more responsibilities, the GDC could provide Dover with alternate technologies and/or solutions. The level of responsibility transfer could be further increased by using the GDC for low volume manufacturing in addition to the design/engineering activities that they would be engaged in. The control system parts, and the pneumatics and hydraulics of the basic structure could follow this route quite quickly.

Key Takeaways

Dover is a quick engineering turnaround company. In such an industry, constant communication between different design/engineering/functional groups is key to achieving time and quality requirements. With the cost pressures that face engineering-intensive businesses, the decision made by Danaher to combine GPD with an offshore outsourcing center was inevitable.

But there are challenges to this hybrid model. Due to the industry's fast-paced nature, design, development and manufacturing often occur simultaneously. Therefore it is often necessary for certain engineers to be on-site. A lot of experience is gained through the touch and feel of the product as it is being developed.

A key observation from this process is that GPD can easily be started with process-based outsourcing; drawing, detailing, and CAD are fairly independent processes that can be outsourced without much disruption. The related software and protocols are, most often, industry norms. There are also immediate cost and productivity benefits from outsourcing. It may be difficult, however, to transition to outsourcing component/sub-system design as doing so would require training and the benefits will not be visible until efficiency is gained. Moreover, a quick engineering turnaround company may not want to risk outsourcing these responsibilities before confidence in the outsourcing centre is achieved.

The DSM architecture will help identify appropriate sourcing strategies.

Case Study 2. Pitney Bowes Mailing Systems: Component Outsourcing

The Company

Pitney Bowes (PB) is a US$5.5 billion company based out of Stamford, Connecticut. Its business encompasses global mail processing solutions, global business services and financial services. PB is the world's largest vendor of mailing systems accounting for more than 50% of the global market in revenue. In addition to its main engineering center in Shelton, Connecticut, the company also has centers in the United Kingdom and France.

Over the years PB has divested the majority of its manufacturing facilities; production of certain core products that require technology, security or systems integration, have remained in-house. By the nature of the mail business, product innovation and development at PB is driven by the postal requirements specified in various countries.

Global Mailstream Solutions is PB's core business. It comprises all of the equipment that PB designs and builds for inserting, sorting and weighing mail, and affixing postage. Traditionally, these machines included meters which had to be "loaded" in post offices and subsequently, through the telephone for postal credit. In 2002, PB introduced Intelli-link, which allows customers to update postage credit online. Intelli-link represents a critical competitive advantage for the company. PB's Global Mailstream Solutions business also offers various mailing and customer communication software solutions.

Global Business Services manages mail facilities at client sites, including document management, incoming/outgoing mail, reprographics, etc.

Financial Services provides the financing and leasing services associated with the sale of PB products.

The MEGA Mailing Systems

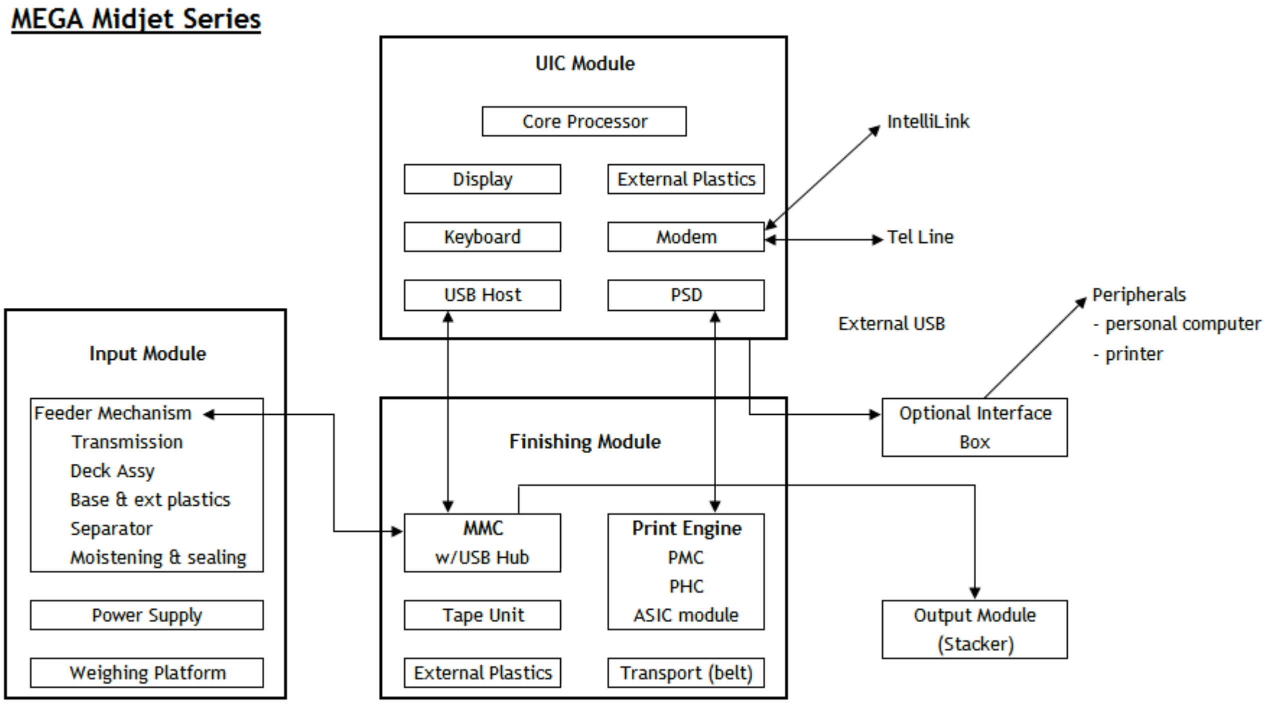
In early 2001, in response to the United States Postal Service's new postal indicia requirements, the growth in IT and electronic media, and the availability of new IT infrastructure, PB began developing a new series of mailing systems: the MEGA Midjet Series and the MEGA Fastjet Series. The new series was developed based on the following guidelines:

a) Electronic exchange of data between customer mailing systems and PB through Intelli-link (e.g., download of postal credit with the required security, software updates, usage information flow back to PB).
b) Single UIC (user interface) part design, compatible across all mailing systems in the MEGA series.
c) Introduction of postal security devices (PSD, ASIC) as mandated by the postal department.
d) Development of a single print head/engine for all MEGA mailing systems.
e) Self-service mailing systems which would provide savings through a reduction of field service needs for both PB and the customer. (Customer would be able to change printer cartridges and control features in UIC, etc.)

Product Architecture

The Fastjet Series, a fully automatic system with an output capacity of up to 260 envelopes per minute, has an integrated input and finishing module. In contrast, the Midjet Series, a semi-automatic system with an output of 160 envelopes per minute, can be decomposed into three main modules: the UIC module, the input module and the finishing module. (See **Figure 2.1**)

Figure 2.1 Schematic of Pitney Bowes MEGA Midjet Series Mail Processing Module



PSD	Postal Security Device
MMC	Motion Control
PMC	Print Maintenance Control
PHC	Print Head Control

The MEGA Midjet Series' UIC portable module contains the postal security device (PSD), an embedded hardware/software unit where the postal credit is stored. The module also holds the modem, USB host, keyboards and display units, components which are required for a customer to interact with the mailing system and for the mailing system to interact with Intelli-link. The core processor, a surface mounted board which contains the unique PB-designed chip, provides all the key functionalities for the mailing systems. The motion control unit (MMC) and the print engine, the two key components of the mailing system that reside outside the UIC, receive information from and provide information to the UIC.

The input module contains the feeder mechanism which receives information/direction from the MMC. It removes each envelope (or sheet or card), transports it for folding, and moistens and seals it. The weighing and sizing of the envelope takes place in the input module and this information is provided back to the PSD, which provides the appropriate postage information to the print engine. The input module also contains the power supply unit and the transmission which converts the electrical energy to motion for the envelope through a system of pulleys.

The finishing module holds the MMC and the print engine. The MMC controls the movement of the envelope. The print engine, supplied by Canon, prints both the indicia and addresses where required. This ASIC unit, designed and provided by PB, contains the postal security information that is transmitted from the PSD. The printer has serviceable parts in the printer head and the print cartridge. The tape unit prints postage and addresses on the tape which, in turn, is pasted on large envelopes on packages.

Product Development at Pitney Bowes

PB follows the PACE product development system which begins with Phase 0, idea screening, wherein the ‘bigger’ picture of the product is generated (e.g. guidelines A-E for the MEGA series). Thereafter, PB follows the standard five phases of product development:

Phase 1: concept development
Phase 2: specifications, planning and feasibility
Phase 3: design and implementation
Phase 4: qualification and readiness
Phase 5: ramp up manufacturing and launch

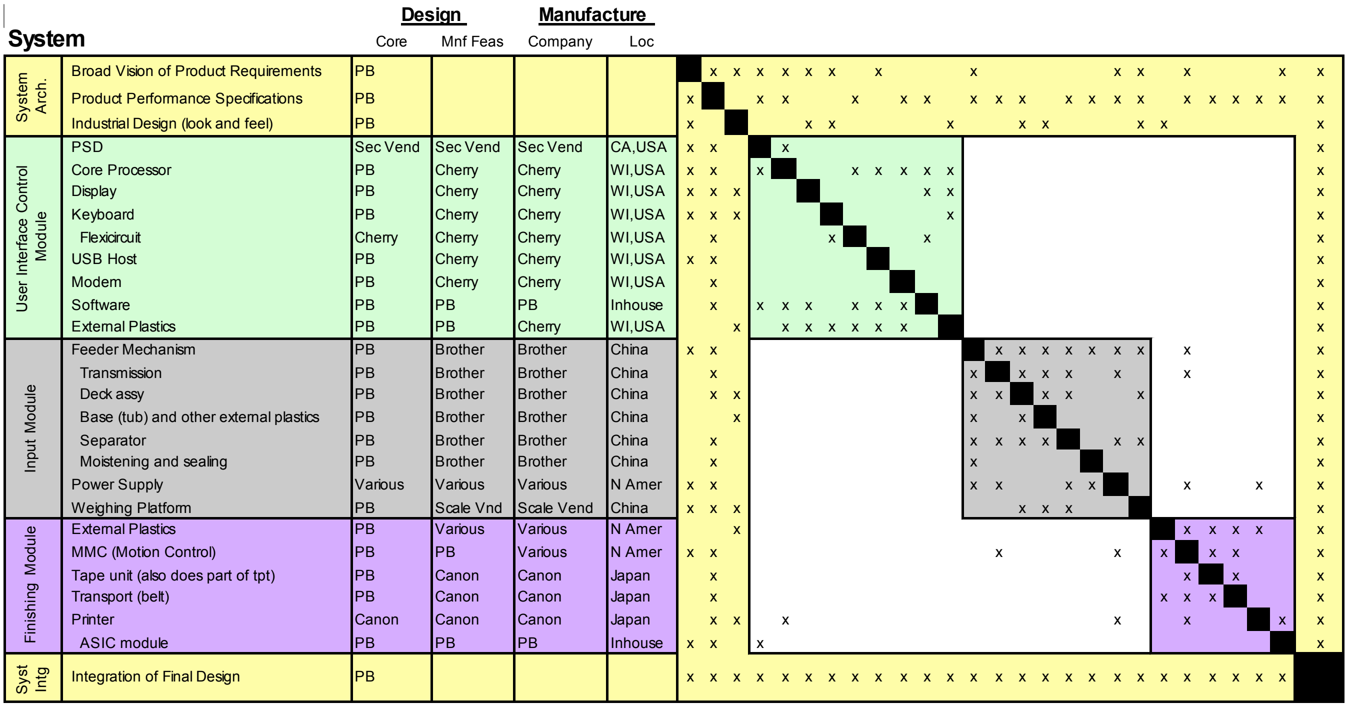
While Phase 0 (idea screening) and the early stages of Phase 1 (concept development) are primarily top-down management decisions, the latter part of Phase 1 and Phase 2 combines top-down directives and bottom-up feasibility assessment. At the time of commitment, the product’s architecture, performance requirements, characteristics of various modules and the parts therein, as well as the roles and responsibilities of various departments and the personnel involved with the product are well defined. At this stage, the time plan for product development is set.

Global Product Development

While most of the components are produced by global suppliers, global engineering for the MEGA Midjet Series is limited to a small portion of software development by China-based CIENET and printer development by Canon. (The UIC's flexi circuit design and the input module's power supply unit are outsourced to U.S. firms.)

Going forward, however, the highly decomposable structure of the MEGA Midjet Series provides several opportunities for PB to further develop GPD. The attached DSM by architecture (**Figure 2.2**) of the MEGA Midjet serves mailing system outlines the sub-systems/parts that comprise the three main systems (UIC, input module, and finishing module). For each sub-system/part, the company having responsibility for core design, manufacturing feasibility sign-off, and manufacturing, respectively, have been identified. Here, Sec Vend against PSD implies that it is designed, studied for manufacturing feasibility, and manufactured by a second vendor, in addition to Pitney Bowes. Cherry, Brother, and Canon, are the key companies that support the design, manufacturing feasibility studies, and sub-system/part manufacturing efforts of the MEGA Midjet mailing system.

Figure 2.2 MEGA Midjet Series Architecture-Based DSM



System		Design		Manufacture																													
		Core	Mnf Feas	Company	Loc																												
System Arch.	Broad Vision of Product Requirements	PB				■	x	x	x	x	x	x		x				x						x	x		x				x	x
	Product Performance Specifications	PB				x	■		x	x			x		x	x		x	x	x		x	x	x	x		x	x	x	x	x	x
	Industrial Design (look and feel)	PB				x		■			x	x					x			x	x				x	x						x
User Interface Control Module	PSD	Sec Vend	Sec Vend	Sec Vend	CA,USA	x	x		■	x																						x
	Core Processor	PB	Cherry	Cherry	WI,USA	x	x		x	■			x	x	x	x	x															x
	Display	PB	Cherry	Cherry	WI,USA	x	x	x			■					x	x															x
	Keyboard	PB	Cherry	Cherry	WI,USA	x	x	x				■					x															x
	Flexicircuit	Cherry	Cherry	Cherry	WI,USA		x					x	■			x																x
	USB Host	PB	Cherry	Cherry	WI,USA	x	x							■																		x
	Modem	PB	Cherry	Cherry	WI,USA		x								■																	x
	Software	PB	PB	PB	Inhouse		x		x	x	x		x	x	x	■																x
	External Plastics	PB	PB	Cherry	WI,USA			x		x	x	x	x	x	x		■															x
Input Module	Feeder Mechanism	PB	Brother	Brother	China	x	x											■	x	x	x	x	x	x	x		x					x
	Transmission	PB	Brother	Brother	China		x											x	■	x	x	x		x			x					x
	Deck assy	PB	Brother	Brother	China		x	x										x	x	■	x	x			x							x
	Base (tub) and other external plastics	PB	Brother	Brother	China			x										x		x	■											x
	Separator	PB	Brother	Brother	China		x											x	x	x	x	■		x	x							x
	Moistening and sealing	PB	Brother	Brother	China		x											x					■									x
	Power Supply	Various	Various	Various	N Amer	x	x											x	x			x	x	■			x			x		x
	Weighing Platform	PB	Scale Vnd	Scale Vend	China	x	x	x												x	x	x			■							x
Finishing Module	External Plastics	PB	Various	Various	N Amer			x																		■	x	x	x	x		x
	MMC (Motion Control)	PB	PB	Various	N Amer	x	x												x					x		x	■	x	x			x
	Tape unit (also does part of tpt)	PB	Canon	Canon	Japan		x																				x	■	x			x
	Transport (belt)	PB	Canon	Canon	Japan		x																			x	x	x	■			x
	Printer	Canon	Canon	Canon	Japan		x	x		x														x			x			■	x	x
	ASIC module	PB	PB	PB	Inhouse	x	x		x																						■	x
Syst Intg	Integration of Final Design	PB				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	■

While the design of the core technology and security components like PSD, MMC, ASIC, along with system integration will likely remain in-house, many of the other components or complete modules could be outsourced for design and development. The architecture-based DSM clearly shows that significant upfront effort is involved in designing the system architecture. The physical and information flow interfaces between the different modules are well identified during this phase, enabling the modules to be developed independently thereafter.

Opportunities

Subsequent to the system architecture phase, each module with its respective interfaces well defined, then proceeded on to independent development. After each module has been developed, there is a system integration phase in which the design and development efforts are integrated for the complete product design. The MEGA Midjet Series' modular architecture presents a number of opportunities for outsource/off-shore development.

One opportunity involves software development (primarily in the UIC and the MMC), which is becoming a significant portion of MEGA Midjet Series' overall product development. While all software work related to feasibility studies, software architecture, and MMC, PSD, and ASIC software for the MEGA Midjet Series will likely remain in-house there is potential to expand the outsourcing of software development, which is currently limited to coding and testing work. With increased confidence in CIENET's competency and level of resources, more software development beyond coding could be outsourced. With proper IP and security protection even non-critical security related software development could be outsourced (though the challenge of outsourcing part of embedded software remains).

A second GPD opportunity for PB involves outsourcing the design and development of the input module. Known for its engineering capabilities, the Chinese manufacturer (Brother affiliate) charged with assembling the MEGA Midjet Series' input module could eventually be responsible for the module's complete design and development. Design and development of the power supply unit could also be included, enabling a complete module design proposal. An alternate design for the power supply unit could feasibly emerge from this arrangement leading to greater cost savings for PB.

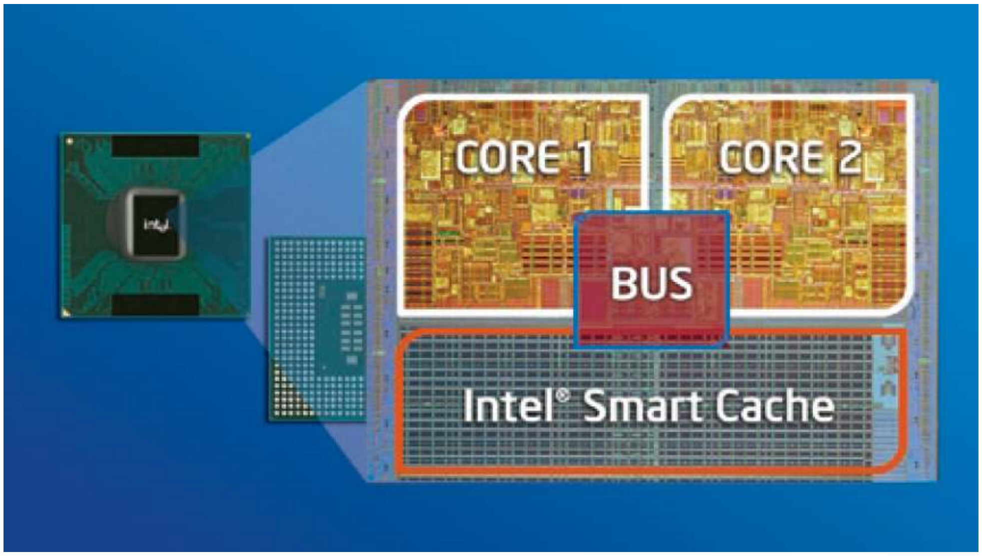
A third opportunity involves the design and development of the entire UIC module. With the exception of the PSD and PB chip, outsourced North American vendors (primarily Cherry) currently manufacture the entire module. However, considering that the UIC uses a number of standard parts, design and development for the module could feasibly be outsourced to vendors outside of North America.

Finally, design and development for the entire finishing module, with the exception of the MMC which is considered a core technology, could feasibly be outsourced to Canon, PB's printer vendor, which is responsible for developing the print engine as well as the transport and tape parts for the finishing module.

Key Takeaways

The architecture-based DSM for PB's MEGA Midjet Series highlights how a product can be well partitioned by modules once the system architecture design has been completed. Such modular architecture can enable each module to be developed independently (out-shore/off-shore/in-house). It also provides an opportunity for manufacturing suppliers to vertically integrate becoming design-cum-manufacturing suppliers, thereby potentially offering synergy benefits.

Case Study 3: Microprocessor Development at Intel: Captive Global Engineering



Intel is an example of a company that keeps GDP within its own worldwide facilities. The company operates a number of engineering facilities which are equal in their microprocessor design and development capabilities.

The Company

Intel designs, fabricates and sells microprocessors, in addition to other products. The design activities for microprocessors are housed out of several off-shore facilities in the United States and Asia. To enable collaboration and transfer of tasks, the design capabilities among the centers are more or less equal. However, with respect to the development of the microprocessor's architecture, there is a certain amount of expertise which exists in each facility. For example, while one site specializes in desktop processors, another site specializes in high-end server microprocessors for industrial applications, and a third is dedicated to mobile microprocessors.

Intel Microprocessor Architecture

The modern high-end multicore microprocessor is made up of two main parts: the core and the uncore (**Figures 3.1** and **3.2**). While, depending on performance requirements there may be many cores, there is only one uncore responsible for supporting the microprocessor and providing the external interfaces.

The core, the heart of the microprocessor unit, retrieves information about the job to be executed, consolidates the information, executes the job (integer execution and floating point execution) and maintains the cache (feeds instructions and holds data until the job is executed and the results are transferred). The uncore, on the other hand, provides all the support that the core needs to execute the job. The uncore consists of the memory controller, both on-socket and system interface off-socket coherency, the inter-socket router—for information flow between the different cores (in case of multicore) and with the environment outside the microprocessor—, the input/output pad, and other miscellaneous units like power maintenance, testing, debugging, etc.

Figure 3.1 Structural Decomposition Diagram of Intel's Multicore Microprocessor

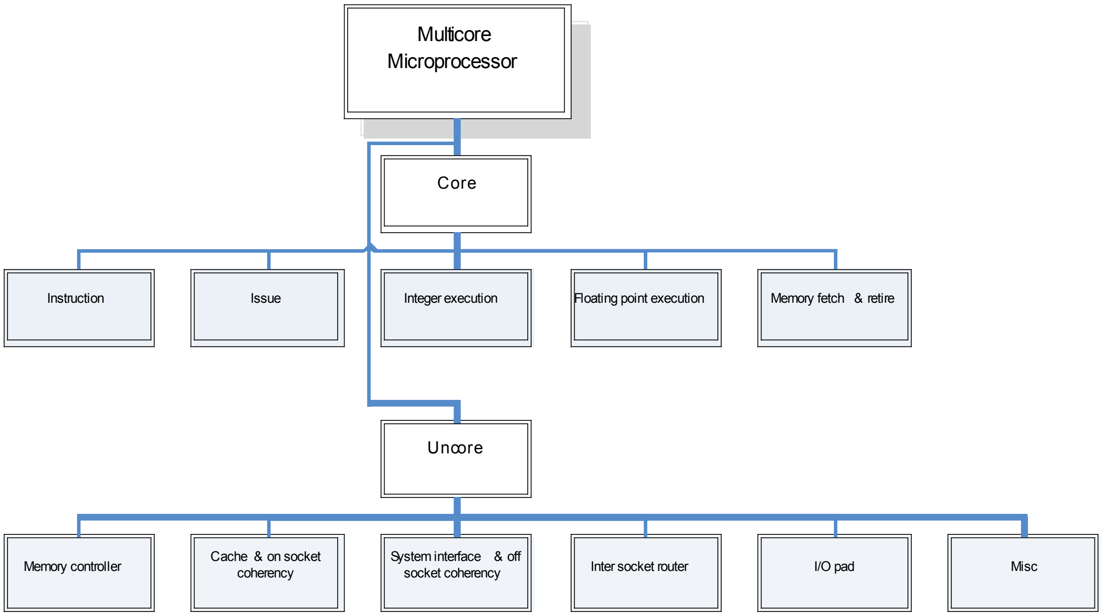
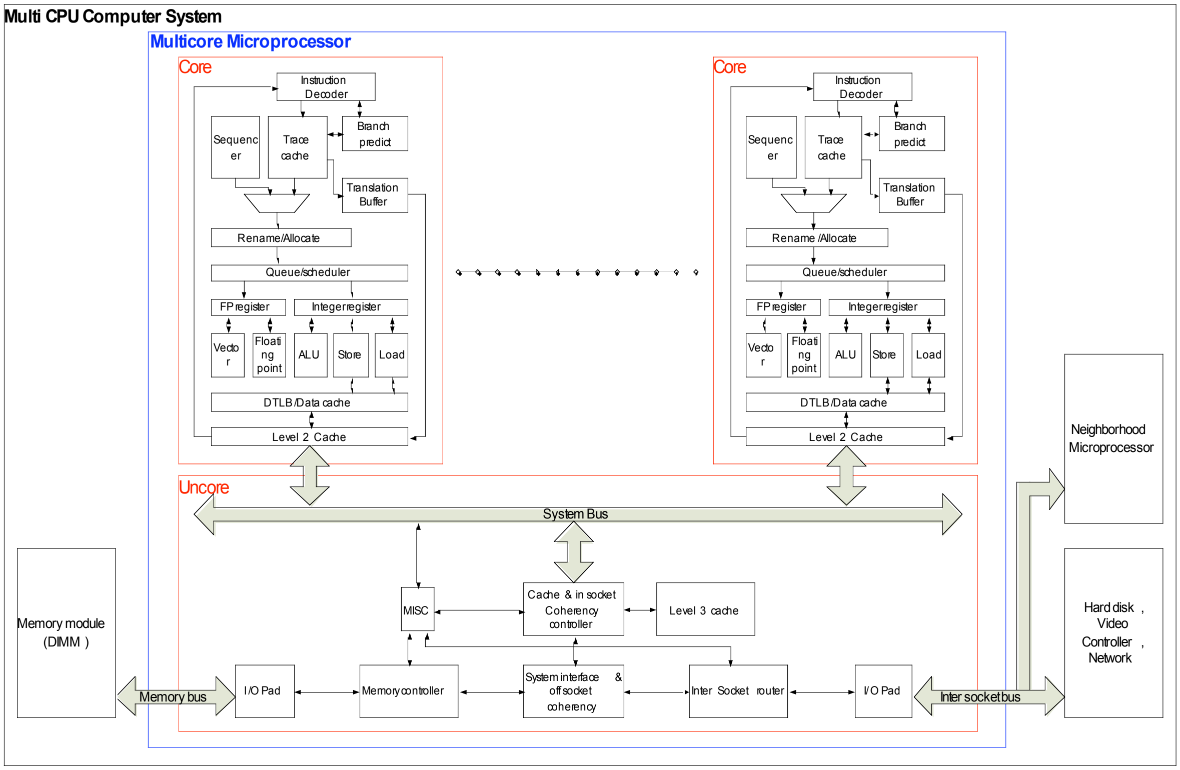


Figure 3.2 Structural and Functional Decomposition Diagram of Multi-CPU Computer System with a Multicore Microprocessor



Microprocessor Design and Development

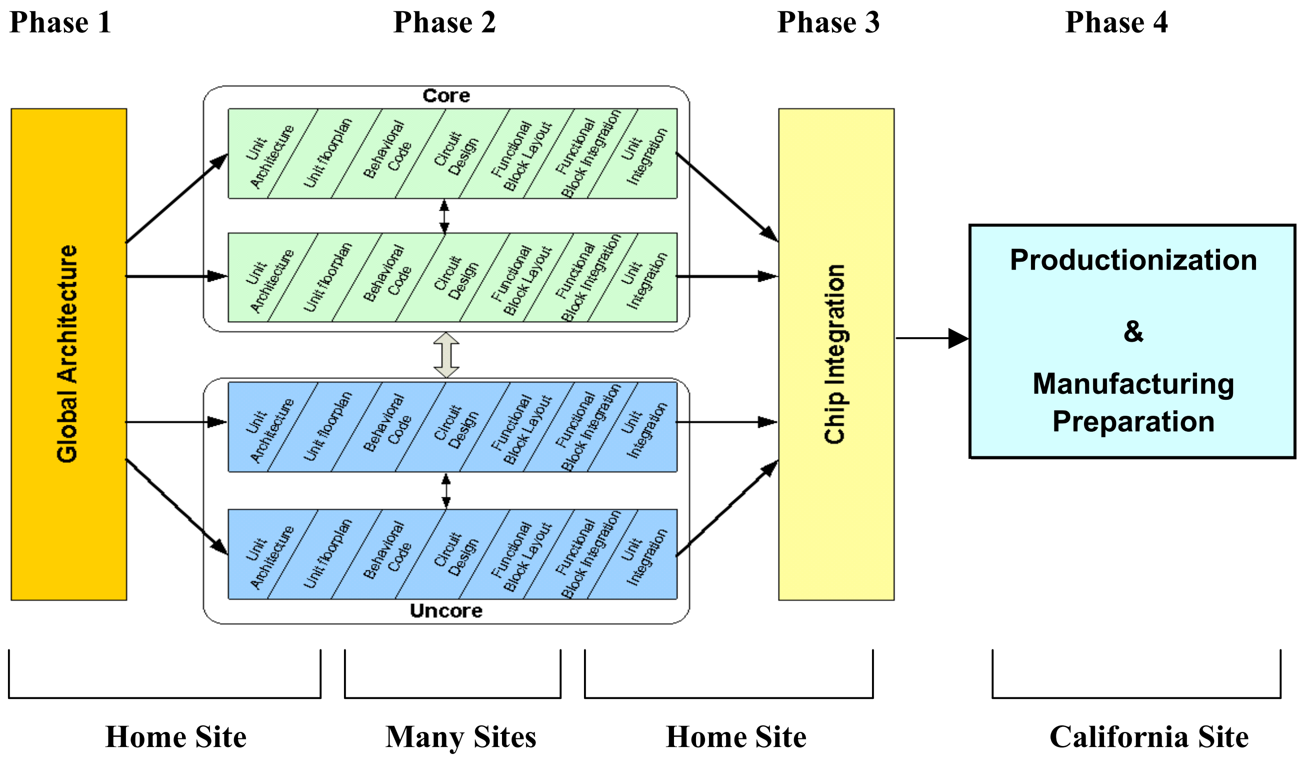
Microprocessor design and development follows a 4-phase, upfront global architecture definition, followed by designs of each unit of the core and the uncore, complete chip integration, and finally, productization and manufacturing preparation.

Design Process Analysis

Although various Intel design facilities specialize in the architecture development of various types of microprocessors, capability to develop core or uncore units are general (rather than specific), and exist in each of the development facilities. As a result, project leaders are able to draw resources from any of the design facilities. If, for example, a microprocessor for mobile technology is being developed, the specialized design team is able to utilize resources from any of the other facilities based on need and availability. Intel regards such flexible resource availability for the design and development of its products as a competitive advantage.

Phase 1 of global architecture development consists of defining the architecture of the chip, the information flows between the different core and uncore units, and development of the unit architecture

Figure 3.3 Microprocessor Design and Development



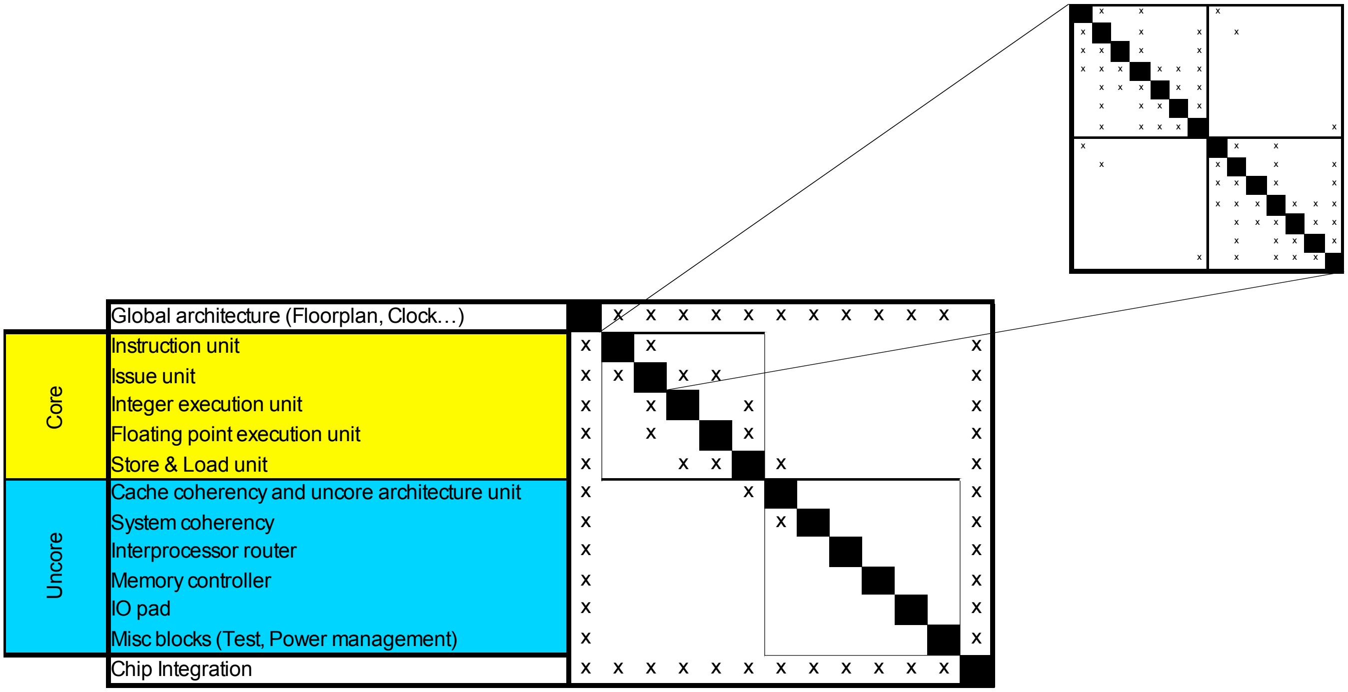
and unit floorplan of the various core and uncore units. During this phase, the team is co-located, usually at the "home site" specializing in the chip type. Thereafter, Phase 2 development can be done in two parts – one team can do the development upto behavioral code stage, and then another team can take over from circuit design until unit integration. Though it may be ideal for the members to be co-located with the project leaders, it is possible for them to work from their respective facilities during this phase. In Phase 3, the designs of the various core and uncore units are integrated per the architecture developed in Phase 1. During this phase, it is necessary for the relevant team members to be co-located at the "home site". The final phase, Phase 4, occurs at California site, where productization and manufacturing preparation of the design takes place. The key development facilities of Intel with their respective specializations are listed below.

Location of Center	**Activity**
California	"productization" of design
Oregon	desktop series microprocessors
Colorado	high-end microprocessor design
Massachusetts	high-end microprocessor design
Israel	mobile technology
Moscow	under development
Bangalore	under development

DSM Development

It was recognized that a pure architecture-based or pure process-based DSM would not explain the relationship intricacies present during microprocessor development. Hence, an architecture-based DSM was first developed and then the key processes in the development of each of the units were added (**Figure 3.5**). The comprehensive DSM is summarized in **Figure 3.4**. The relationships between various units/processes were then identified and quantified. Ratings of “A”, “B” or “C” were assigned based on the impact of one process on another process. Relationships that received an “A” rating would likely require a 50-100% revision of the upstream task, “B”, a 20-50% revision, and “C”, less than a 20% revision.

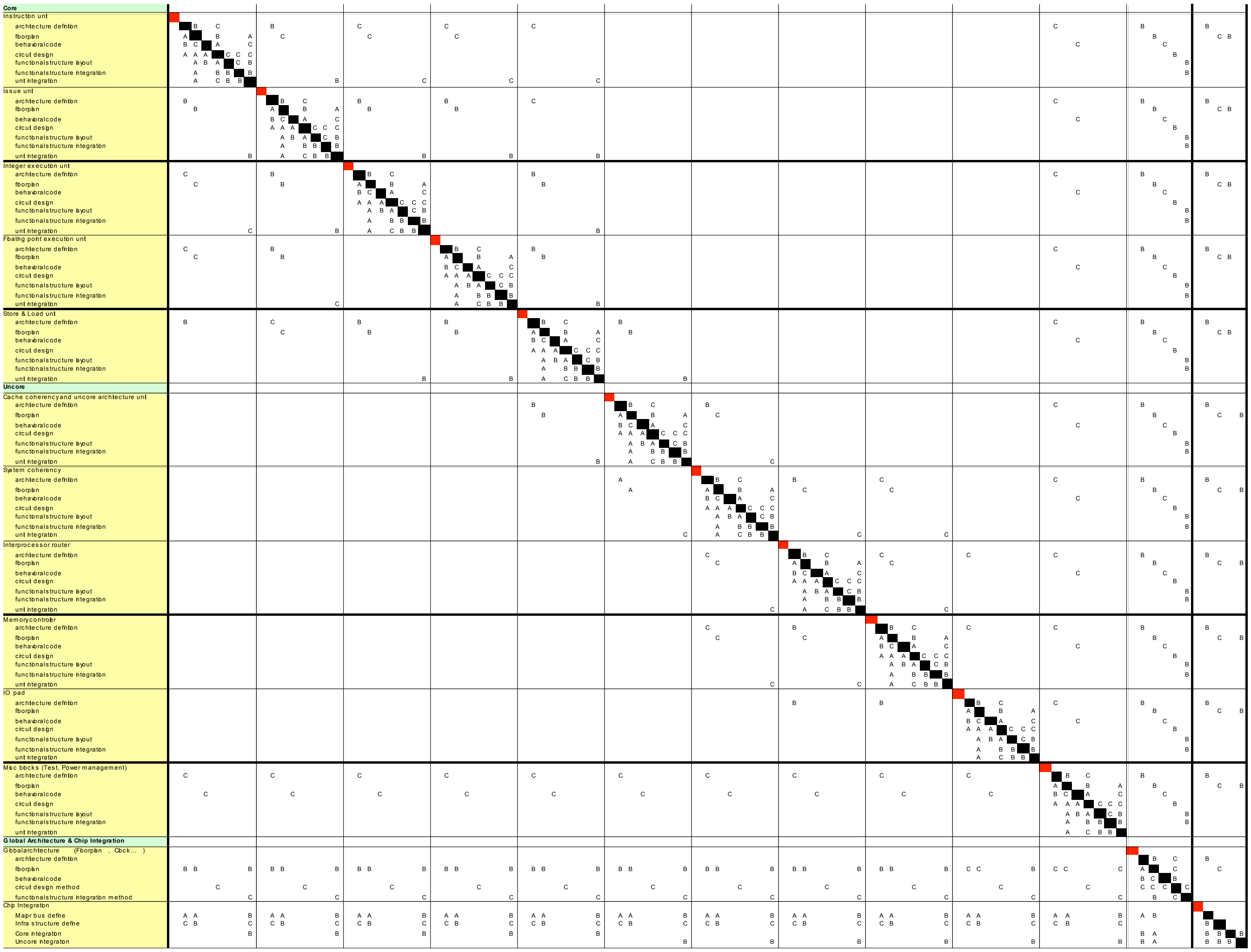
Figure 3.4 Microprocessor DSM Summary



	Global architecture (Floorplan, Clock…)	■	x	x	x	x	x	x	x	x	x	x	x	
Core	Instruction unit	x	■	x										x
	Issue unit	x	x	■	x	x								x
	Integer execution unit	x		x	■		x							x
	Floating point execution unit	x		x		■	x							x
	Store & Load unit	x			x	x	■	x						x
Uncore	Cache coherency and uncore architecture unit	x					x	■						x
	System coherency	x						x	■					x
	Interprocessor router	x								■				x
	Memory controller	x									■			x
	IO pad	x										■		x
	Misc blocks (Test, Power management)	x											■	x
	Chip Integration	x	x	x	x	x	x	x	x	x	x	x	x	■

A review of the relationships showed that most “A” ratings existing within the core or uncore units. Moreover such high rework possibilities only existed during Phase 2 (unit design) and Phase 3 (chip integration). This can be deduced as a strength of Intel’s upfront global architecture development efforts (Phase 1), wherein the various unit design efforts are self-contained from Phase 2. This also provides an opportunity for the `unit’ teams to work individually, and it is not necessary for the various teams to be co-located. The other “A’ ratings occur during chip integration phase (Phase 3) when all the team members are co-located. There are no “A” ratings in Phase 3 that may require a review of any of the Phase 1 or Phase 2 activities.

Figure 3.5 Microprocessor Comprehensive DSM



There are a couple of “A” rated interactions/dependencies across units. However, these interactions occur during the unit architecture and unit floorplan part of design when the team is co-located. Hence, any big revision arising from these interactions/dependencies should be manageable. Similarly, most of the “B’ rated interactions/dependencies occur, either, during Phase 1 or Phase 3 (when the team is co-located) or within the core and uncore units. Thus, they can be managed within co-located teams.

Some takeaways from the microprocessor DSM are:

1. The formation of unit-based teams is obvious as most interactions/dependencies exist within the core or uncore unit after Phase 1.
2. Significant efforts in Phase 1 (approximately 50% of the microprocessor design time) ensure that units can be developed independently thereafter, until the final phase of chip integration (Phase 3).

3. During Phase 2, individual unit teams can continue design work independently, and need not be co-located with other teams. This gives Intel the flexibility of using resources from different design centers for different unit designs – this is a very useful flexibility to have when balancing workload.
4. Chip integration (Phase 3) does require the team to be co-located. However, the total team strength is quite reduced at this phase since limited representation from the respective unit teams would suffice.

Case Study 4: Aircraft Development at Cessna: Supplier Co-Development

The Company

Founded in 1927, Cessna Aircraft (Cessna) is the world's leading designer and manufacturer of light and mid-size business jets, utility turboprops, and single engine piston aircraft. In its nearly 80-year history, Cessna has delivered more than 180,000 airplanes. The Citation, manufactured by Cessna, is the world's largest fleet of business jets.

Cessna, a part of the $10 billion Textron group, is headquartered in Wichita, Kansas, where it also has its main manufacturing facility, and engineering and product development center. Additional manufacturing facilities are located in Independence, Kansas and Columbus, Georgia. Cessna also operates a number of service centers worldwide.

Product Development at Cessna

Unlike many of its competitors, Cessna's aircraft design and development activities are vertically integrated; most design efforts for aerodynamics, structures, and systems integration and most of the product-level testing are carried out in-house. In comparison, Bombardier, Embraer, and Gulfstream outsource a larger portion of their development efforts. Of Cessna's 12,000 employees, 2,300 make up the company's engineering design and development group. Cessna's jet aircraft product line accounts for the majority of the company's product development efforts.

A First Attempt at GPD: Supplier Co-Development

Cessna's first attempt at GPD was based on a realization that, going forward, it would be challenging to do all design work in-house. Thus Cessna decided to experiment with GPD in a new aircraft program by co-developing a complete aircraft section jointly with a key supplier.

The challenges that arose from that first experience proved to be valuable learnings for the company. While Cessna used the supplier's engineers to carry out part of the design work it required that Cessna processes and standards be followed. The tension between Cessna's involvement and the supplier's desire for independence proved to be a source of friction and eventually led Cessna to select a second source for production of this section.

The company realized that in the future, it might be more prudent to outline product performance specifications and grant more decision-making authority to the supplier on structural design, manufacturing standards and processes. Despite the tensions that arose between the company and the supplier, many Cessna executives understood that significant learning took place on both sides and said that they would work with the same supplier again.

Second GPD Stage: Textron's Global Technology Center

Cessna's second GPD effort was in direct response to impressive growth expectations. After suffering a significant downturn during 2001-03, the cyclical business jet industry bounced back; the business segments in which Cessna operates are expected to grow by more than 100% between 2004 and 2009. Recognizing the tremendous growth opportunity, Cessna performed an internal assessment of its design, development, manufacturing capabilities, and its ability to capitalize on growth expectations. Given the short lead time available to meet the incremental requirements and cost factors involved, Cessna concluded that the growth opportunities could be met through outsourced design and development (not just build-to-print). Product architecture development and system integration, however, would remain in-house to ensure that the brand “DNA” was not compromised.

In 2004, Cessna’s parent company, Textron, established the Global Technology Center (GTC), a corporate sponsored engineering resource center located in Bangalore, India, as an effort to provide lower cost and capable engineering capacity to group companies. Within a period of two years, Cessna hired and trained engineers in various technical specialties. In addition, the company identified available capability in certain aircraft development activities with a second Indian vendor.

In 2006, Cessna was operating under a small scale GPD model wherein a supplier’s employees, co-located at the GTC, worked on tasks that matched their capabilities. Concurrently, Cessna was developing Cessna-dedicated GTC employees on specialized jobs with an aim of achieving system/sub-system design and development capability within a few years.

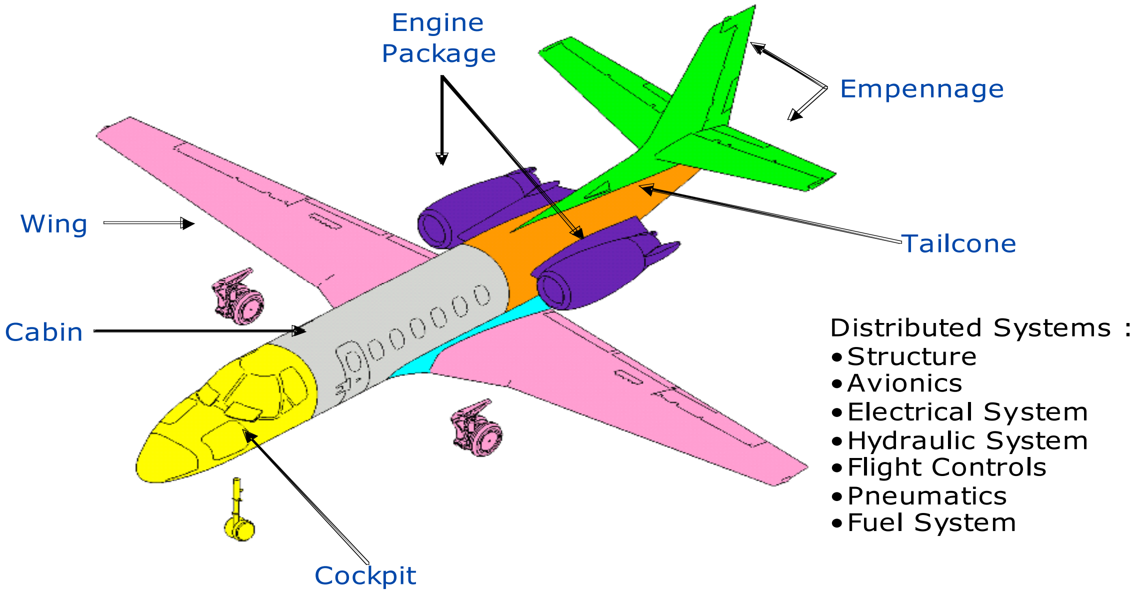
The System Architecture-Based DSM

The high-level architecture-based DSM, based on inputs from Cessna’s system architecture group, indicates that modular decomposition for Cessna’s jet aircraft is not possible. Developing the DSM was challenging, as the architecture can be defined either by functional systems like electricals, hydraulics, pneumatics, etc. or by sections like cockpit, cabin, etc. The functional systems are distributed throughout the aircraft, touching almost all sections. Similarly, each section contains elements of most of the functional systems. For example, the electrical system starts at the cockpit, and runs through the cabin, the tailcone, the wings, and the engine.

The section-based DSM developed should provide key insights about the interdependencies/interactions between major aircraft sections and functional systems. The aircraft can be divided into six different ‘section-based’ systems – cockpit, cabin, tailcone, wings, empennage, and engine package (**Figure 4.1**). Each section comprises of structural sub-systems/components that are unique to that section, eg. shell and structure in the cockpit, and functional systems.

The DSM developed (**Figure 4.2**) considers, for each section, those functional systems that have a significant role, eg flight controls in cockpit, wings and empennage, fuel systems in wings and engine package, etc. The system architecture integrates all of them. At the overall system level, the product requirements are developed through sharing information with structural/functional systems like structure, avionics, electrical system, etc. These product level requirements for the structure/functional systems, are in turn, developed through information exchange with the respective functions in the sections (the information from and to the functional systems of system architecture in the DSM). As is evident from the DSM, most interactions are contained within sections, though some interactions/information dependencies occur between sections. Such interactions/ information dependencies will need to be managed if the teams developing the respective sections are not co-located.

Figure 4.1 Typical Aircraft Sections

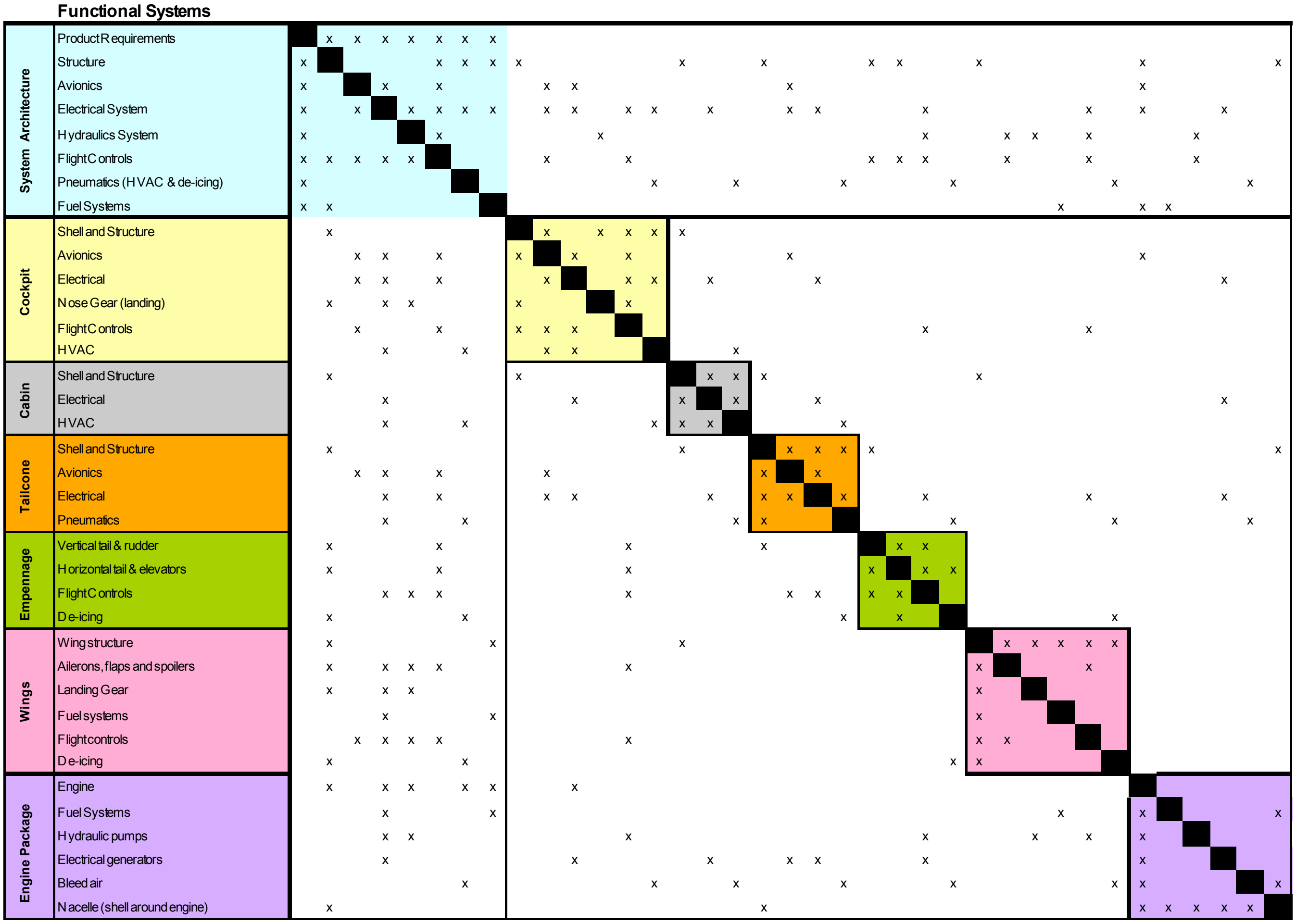


Findings/Observations

Some of the key takeaways from the study are:

a) **Co-Location**: Clearly, as Cessna considers moving from its current vertically integrated development structure to a horizontal one, sources providing design capabilities will play a key role. The strong dependencies of each of the systems/sub-systems on the product architecture (as evidenced from the DSM) clearly point towards co-location of the providers with Cessna engineers, at least in the early part of the program when the package and specifications are developed. Subsequent co-location would depend on the level of interaction required. The DSM would need to be expanded to identify the relevant interactions that would require co-location.

Figure 4.2 System Architecture based DSM



	Functional Systems																																					
System Architecture	Product Requirements	■	x	x	x	x	x	x	x																													
	Structure	x	■				x	x	x	x						x			x				x	x			x						x					x
	Avionics	x		■	x		x				x	x								x													x					
	Electrical System	x		x	■	x	x	x	x		x	x		x	x		x			x	x				x						x		x			x		
	Hydraulics System	x				■	x						x												x			x	x		x				x			
	Flight Controls	x	x	x	x	x	■				x			x									x	x	x			x			x				x			
	Pneumatics (HVAC & de-icing)	x						■							x			x				x				x						x					x	
	Fuel Systems	x	x						■																					x			x	x				
Cockpit	Shell and Structure		x							■	x		x	x	x	x																						
	Avionics			x	x		x			x	■	x		x						x													x					
	Electrical			x	x		x				x	■		x	x		x				x															x		
	Nose Gear (landing)		x		x	x				x			■	x																								
	Flight Controls			x			x			x	x	x		■											x						x							
	HVAC				x			x			x	x			■			x																				
Cabin	Shell and Structure		x							x						■	x	x	x								x											
	Electrical				x							x				x	■	x			x															x		
	HVAC				x			x							x	x	x	■				x																
Tailcone	Shell and Structure		x													x			■	x	x	x	x															x
	Avionics			x	x		x				x								x	■	x																	
	Electrical				x		x				x	x					x		x	x	■	x			x						x					x		
	Pneumatics				x			x										x	x			■				x						x					x	
Empennage	Vertical tail & rudder		x				x							x					x				■	x	x													
	Horizontal tail & elevators		x				x							x									x	■	x	x												
	Flight Controls				x	x	x							x						x	x		x	x	■													
	De-icing		x					x														x		x		■						x						
Wings	Wing structure		x						x							x											■	x	x	x	x	x						
	Ailerons, flaps and spoilers		x		x	x	x							x													x	■			x							
	Landing Gear		x		x	x																					x		■									
	Fuel systems				x				x																		x			■								
	Flight controls			x	x	x	x							x													x	x			■							
	De-icing		x					x																		x	x					■						
Engine Package	Engine		x		x	x		x	x			x																					■					
	Fuel Systems				x				x																					x			x	■				x
	Hydraulic pumps				x	x								x											x				x		x		x		■			
	Electrical generators				x							x					x			x	x				x								x			■		
	Bleed air							x							x			x				x				x						x	x				■	x
	Nacelle (shell around engine)		x																x														x	x	x	x	x	■

b) **Systems Interactions:** The DSM shows interactions between functional sub-systems – electrical, flight controls, pneumatics, etc.; however, the exact nature and details of these interactions need to be studied further. Such a study will help determine the need for Cessna personnel involvement (and the number of people needed) if the systems are provided by different suppliers. A clear roles and responsibilities (R&R) may need to be developed in that case.

c) **Culture:** Cessna follows the standard Textron 7-stage New Products and Services Introduction (NPSI) process. If Cessna moves to a more horizontal structure (more outsourced design and development), the stage timings and applicable processes may need to be modified/updated to reflect the upstream involvement of suppliers providing design capabilities and aircraft industry standards. Most of these sources operate in the wider aviation industry and it may be very difficult to have them adopt 'Cessna-specific' practices.

Meanwhile, Cessna engineers will be challenged with learning to work with outsourced suppliers whose practices may not mirror those followed at Cessna.

d) **Definitions:** Cessna would likely face a dilemma in terms of defining systems/sub-systems for suppliers to design due to the high level of interactions presented in the DSM. Though the systems in this DSM have been defined in terms of 'sectional' systems, it is also possible to develop a DSM based purely on functional lines, e.g., electrical, pneumatics, etc, and in line with the sourcing strategy being considered – e.g., a single supplier who provides all the electrical wirings versus a wing supplier who is responsible for all the electricals within his scope of supply.

Cessna is currently in the midst of an exciting phase. The DSM tool may be used in different ways to aid a transition to a horizontally integrated product development environment.

Case Study 5: Honeywell – Aerospace Division: Task Based Offshoring

The Company

Honeywell International Inc. is a $31 billion diversified company headquartered in Morristown, New Jersey. Its roots can be traced back to 1886 with the founding of the Butz Thermo-Electric Regulator Company, which eventually became the Minneapolis Heat Regulator Company, the first company to patent an electric motor. The company's 1927 merger with Honeywell Heating Specialty Company was the first of many mergers, acquisitions and joint ventures that involved companies including Brown Instrument Co. (controls and pyrometer), Doelcam Corp (gyroscopes), Sperry Aerospace (avionics), Pioneer, Lycoming, Garret, Grimes, and Allied Signal (aerospace, specialty materials, automotive).

Honeywell's products span four key areas:

- Aerospace: engines, avionics, aircraft components

- Automation and Control Solutions: safety systems for homes, buildings, industrial sites, airports
- Specialty Materials: chemicals, fluorocarbons, advanced fibers
- Transportation Systems: automotive turbo systems, friction materials

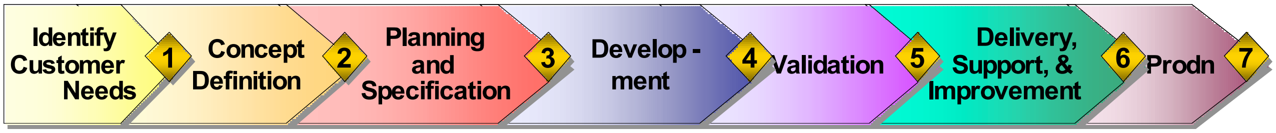
Honeywell Aerospace

Phoenix-based Honeywell Aerospace, a $9 billion division of Honeywell, is a leading industry supplier of avionics and electronics, consumable hardware, engine controls, environment controls, landing systems, power systems, and propulsion engines to the defense, space and airline industries. The division has design and development centers located at several U.S. product sites. This case study focuses on Honeywell Aerospace's avionics operations.

Product Development

Honeywell Aerospace follows a 7-phase integrated product development process:

Phase 1: identification of customer needs
Phase 2: concept definition
Phase 3: planning and specification
Phase 4: development
Phase 5: validation
Phase 6: delivery, support, and improvement
Phase 7: production



These stages are followed for new product introduction and cost reduction activities on existing products (also known as value engineering activities).

The complexity of the products that Honeywell Aerospace manufactures warrants a strong level of interaction and collaboration between design, marketing, planning, and an integrated supply chain to meet program cost, quality, and timing objectives. A growing competitive landscape has led to increased cost pressures, more challenging schedule requirements, and rising manufacturing and quality expectations.

GPD Dilemma

The Advanced Manufacturing Engineering (AME) group was created within the Aerospace Integrated Supply Chain in 2005. Its charter is to drive down program costs by enhancing collaboration between different participants of the product development process.

As AME grows, it will face local hiring constraints (due to cost) and, per the mandate of Honeywell's CEO, the group will have to look to hire internationally, particularly in low-cost regions. Labor costs, efficiency and co-ordination efforts will all be considered with any decision AME makes regarding off-shoring. The AME group was considering three location options for Honeywell Aerospace's design and development activities:

Local	current site, close to/near other departments that they need to collaborate with, e.g., Phoenix, New Jersey
Medium Cost	close to current location, with close time-zones, allowing certain "customer-constrained" jobs to be moved there, cheaper labor costs than local, e.g., Puerto Rico, rural United states
Low Cost	distant location with cheapest labor costs, e.g., India, China

Any location option that AME chooses will involve various costs including:

a) Labor costs related to manpower (time in hours).
b) Co-ordination and collaboration costs related to the time spent carrying out tasks which involve information sharing/transfer.
c) Fixed costs related to setting up new facilities, hiring and training, etc.

There are likely to be constraints in the form of:

a) Potential capacity (manpower) at off-shore locations.
b) AME tasks that are required to be executed locally.
c) AME tasks that need to be co-located with other tasks (including non-AME tasks).

Decision-Making Approach

Each of the three options that the AME group was contemplating came with risks. For example, while resulting in lower labor costs, it was evident that moving tasks from local operations to medium cost or low cost locations would require more co-ordination and collaboration time and, therefore, costs. Honeywell had to ensure that an appropriate trade-off, such as lower labor costs against higher coordination and collaboration costs, was achieved prior to off-shoring certain tasks. The AME group went through the following steps to determine the tasks that could be off-shored.

Step 1: A full list of tasks that AME is responsible for carrying out was generated. Tasks that had to remain on-shore were identified while groups of tasks that needed to be co-located were bundled as single tasks.

Step 2: A (numerical) design structure matrix (DSM) was built (**Figure 5.1**). As shown, there are nine sections in the DSM. Each section represents a combination based on the relative locations of a pair of tasks (local, medium cost country, low cost country). One of these sections has been expanded in **Figure 5.2**. The rows (and columns) list each of the AME tasks that could be off-shored and each of the other departments that AME interact with (design, integrated supply chain, and marketing and program management – these departments are constrained to be local).

Figure 5.1 Task-Based DSM (Structure)

	Local	Medium Cost	Low Cost
Local	Figure 2		
Medium Cost			
Low Cost			

Step 3: For each task under consideration, the estimated labor time per task for all aerospace programs was expressed in hours per month. The DSM captured the approximate hours of interaction between various tasks – coordination time in hours per month. **Figure 5.2** is a sample drawn from the DSM. The co-ordination time between task `Should-Cost Modeling' and Engineering is 60 hours when this task is done locally (shown as A in **Figure 5.3**). Similarly, the coordination time between tasks `Should-Cost Modeling' and `Quote Acquisition' is 10 hours when both the tasks are done locally (shown by B in **Figure 5.3**), but increases to 15 hours when `Quote Acquisition' is done in a medium cost country (shown by C in **Figure 5.3**). These coordination times obtained from the DSM were used to derive the coordination costs.

Step 4: For each potential location, the hourly (relative) labor costs and relative efficiencies for carrying out each task were identified. These helped determine the labor and coordination costs used in the model (using the coordination time from the DSM).

Step 5: An optimization problem was developed to identify the locations for various tasks.

Figure 5.2 One Section of DSM

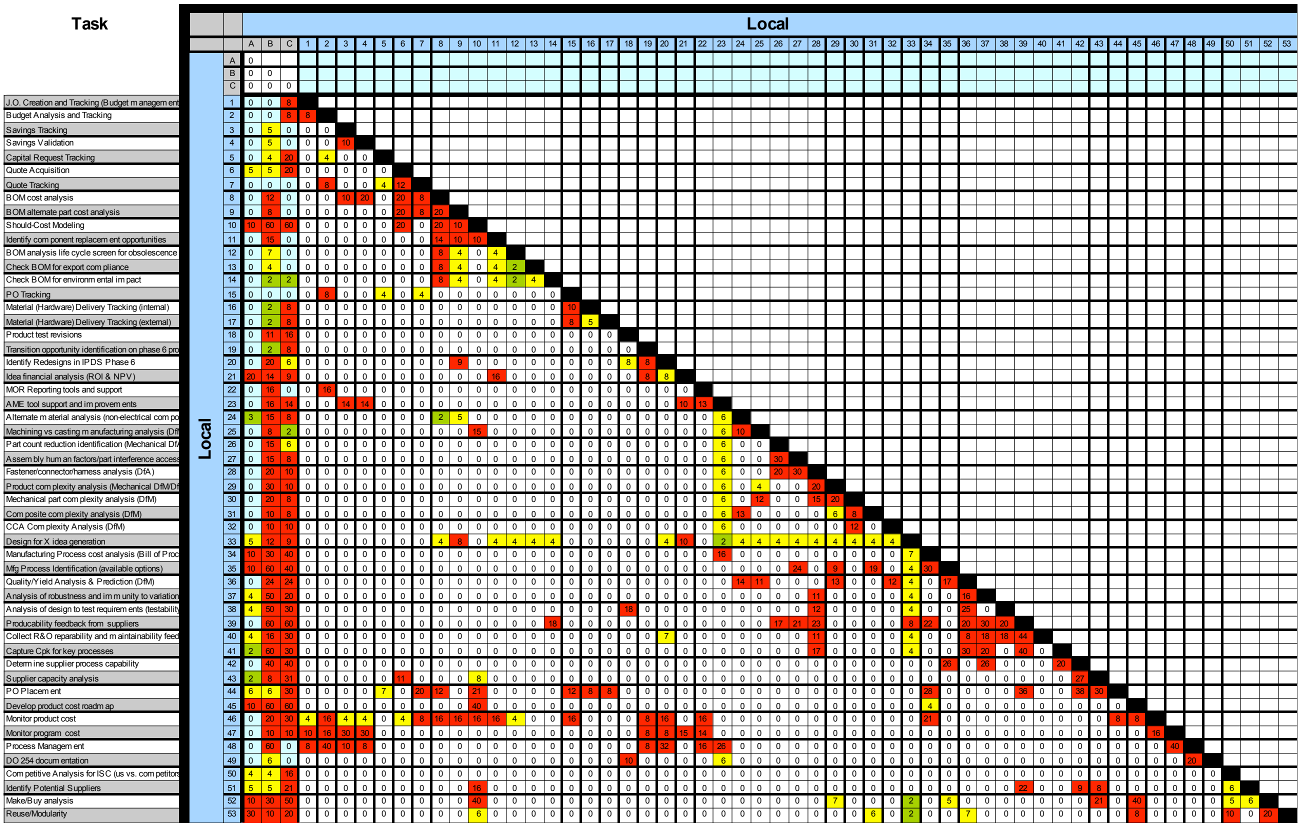
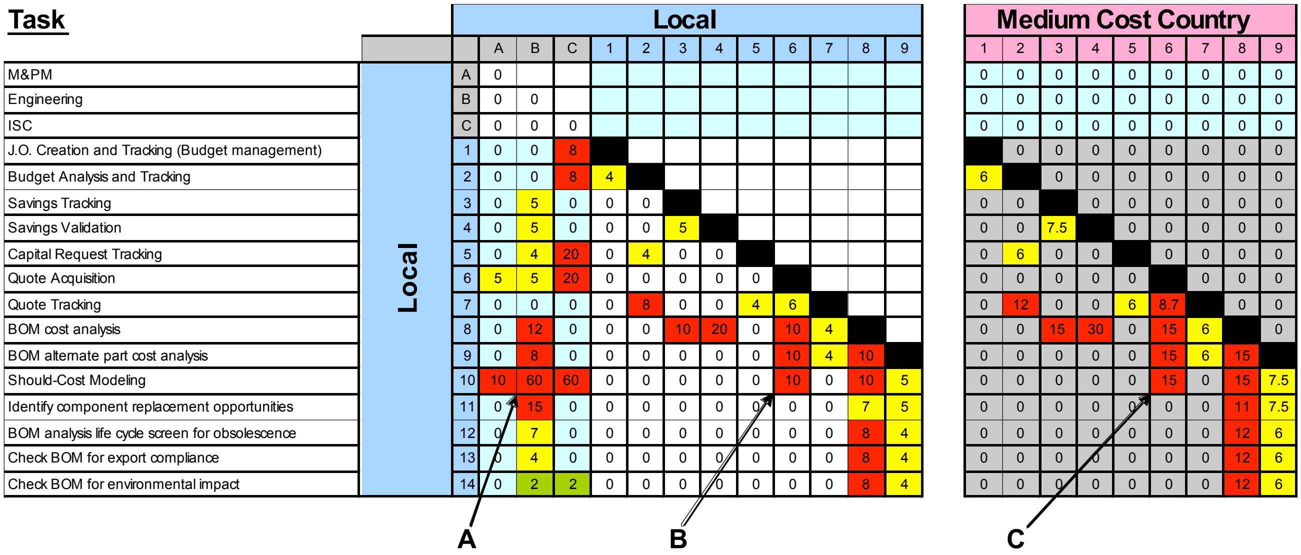


Figure 5.3 Sample DSM cutout



Task		Local												Medium Cost Country								
		A	B	C	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
M&PM	A	0												0	0	0	0	0	0	0	0	0
Engineering	B	0	0											0	0	0	0	0	0	0	0	0
ISC	C	0	0	0										0	0	0	0	0	0	0	0	0
J.O. Creation and Tracking (Budget management)	1	0	0	8											0	0	0	0	0	0	0	0
Budget Analysis and Tracking	2	0	0	8	4									6		0	0	0	0	0	0	0
Savings Tracking	3	0	5	0	0	0								0	0		0	0	0	0	0	0
Savings Validation	4	0	5	0	0	0	5							0	0	7.5		0	0	0	0	0
Capital Request Tracking	5	0	4	20	0	4	0	0						0	6	0	0		0	0	0	0
Quote Acquisition	6	5	5	20	0	0	0	0	0					0	0	0	0	0		0	0	0
Quote Tracking	7	0	0	0	0	8	0	0	4	6				0	12	0	0	6	8.7		0	0
BOM cost analysis	8	0	12	0	0	0	10	20	0	10	4			0	0	15	30	0	15	6		0
BOM alternate part cost analysis	9	0	8	0	0	0	0	0	0	10	4	10		0	0	0	0	0	15	6	15	
Should-Cost Modeling	10	10	60	60	0	0	0	0	0	10	0	10	5	0	0	0	0	0	15	0	15	7.5
Identify component replacement opportunities	11	0	15	0	0	0	0	0	0	0	0	7	5	0	0	0	0	0	0	0	11	7.5
BOM analysis life cycle screen for obsolescence	12	0	7	0	0	0	0	0	0	0	0	8	4	0	0	0	0	0	0	0	12	6
Check BOM for export compliance	13	0	4	0	0	0	0	0	0	0	0	8	4	0	0	0	0	0	0	0	12	6
Check BOM for environmental impact	14	0	2	2	0	0	0	0	0	0	0	8	4	0	0	0	0	0	0	0	12	6

Key Decisions

Subsequent to the above steps, Honeywell was able to identify tasks that could be off-shored to a medium and a low cost location. The medium cost location was chosen on account of its skilled workforce and the ease of coordinating work with the United States. Based on skill requirements and task interactions defined in the DSM, tasks were grouped together and turned into job descriptions. During this time, AME went through a structural reorganization, enabling it to add management to support the planned global activities.

Learnings from the Case Studies and Directions for Future Work

Ghemawat (2007) proposes a AAA triangle framework to help businesses to develop strategies for their operations, to respond to globalization. This framework's strategies are adaptation (country-specific actions to boost revenue and market share by maximizing a firm's local relevance), aggregation (create economies of scale through regional operations, often involving standardization), and arbitrage (exploit differences in capabilities and competencies along the supply chain). The same draws a parallel to the definition of GPD put forth by Eppinger and Chitkara (2006). However, GPD need not necessarily be constrained as a reaction to `market' globalization but could also be a reaction to competitive pressures in the home market or recognition of an opportunity to arbitrage (discussed earlier). Each of the five case studies appear to fall into the later category of either competitive pressures or opportunity of arbitrage driving GPD.

Though each of the companies proceeded to GPD for the same reasons, they all had different approaches and encountered different results. While one company had to change an offshore source (coupling of bad experience and corporate direction) – Danaher Motion/Dover; another relies on the technical superiority of an offshore supplier's component (Pitney Bowes for Canon's printer technology); a third company believes in replicating similar engineering centers in all locations (Intel); a forth (Cessna) tried GPD as an experience which did not meet their expectations but more importantly, they reviewed their experience and believe that GPD is the way forward and are actively participating in an offshore PD centre through a mix of inhouse and outsource PD activities; and a fifth (Honeywell Aerospace) looked at sourcing manpower at multiple locations for a new department to benefit from lower labor costs. Clearly there is no single framework/approach that can accommodate all the above cases. However, two significant inferences can be made:

a) The insource/outsource (make/buy) decision and onshore/offshore decision can happen in parallel for GPD (Khurana (2006) alluded to the same). They are independent until the stage of source selection where there could be a possibility of non-availability of appropriate external source and hence the decision to insource. Thus, it is a 2 x 2 matrix and the company needs to decide where they may want to be for each process/sub-process/task or system/sub-system/component. This decision could be driven by the need to protect core competence or intellectual capability, availability of appropriate sources for outsourcing, ability to appropriately and adequately decompose the process or product, etc.

b) The principles of system architecture and the relevant tools in it can be used as effective tools to help decompose processes and products appropriately for GPD. It is difficult to envisage the complete offshoring of a development process or the development of a product through a single phase, rather it is expected to progress in phases. System architecture helps to identify the sets of processes or sub-systems/components that can be offshored together.

Amongst the various inferences and future potential research directions that emerge from the case studies, the key could be those that address why the firms are doing GPD, how they are doing GPD and the rationale for the same, and what are the key challenges that they face in GPD and the corresponding decisions that they take.

As outlined earlier, the case studies have clearly shown that the mode of sourcing (make/buy) and location for sourcing (onshore/offshore) are parallel decisions. It is important for a firm to identify its core competence and intellectual properties, and which of those they would be willing to share. In complex engineered products, core competence or intellectual property is primarily a sub-system or a component of the final product, and rarely the complete product. Novak and Eppinger (2001) found that there existed strong complementarity between complexity in product design and vertical integration of production, with in-house production being more attractive when product complexity is high. This drives an idea for research along the lines – Using system architecture tools, how easy or difficult is it to decompose a complex product so that GPD of sub-systems/components can be pursued? What is the relationship between design complexity and design integration (vertical and horizontal)? Further, in light of Henderson and Clark's (1990) observation that architectural knowledge tends to become embedded in the structure and information processing procedures of established organizations, it may be worthwhile to see if GPD opportunities (either pursued due to adaptation or arbitrage reasons) drive architectural changes and if they do, how does that impact the firm?

In parallel, the firm will need to identify the key reasons driving the onshore/offshore decision. As seen in the case of Cessna, the company expects a significant growth in the near future and is working on utilizing the GTC set up by Textron for the same. They are following a dual approach – they have identified core and mission critical tasks and would keep these inhouse at the GTC, but will utilize available knowledge (outsource) for non-core and non-critical tasks. In contrast, Dover's quick engineering turnaround and expertise is built around air bearing technology and they intend to keep that core competence/knowledge inhouse and onshore, while progressively outsourcing and offshoring other tasks and sub-systems/components. Pitney Bowes products include printer technology as a core competence, but this product is outsourced and offshored – displaying a strong partnership between Pitney Bowes and their supplier Canon. Thus with no clear trend visible, it may be interesting to research the relationship between these decisions. The reasons leading the company to GPD would weigh in quite heavily while determining the relationship.

Even if the firm is able to identify its core competence and intellectual property that it would want to retain in house, it may still be very difficult to outsource the remaining due to the information flows, linkages, dependencies, etc. present between the identified in-house and outsource processes/sub-systems/parts. System architecture can play a very useful role here. Clearly the outsourced package is invariably less than the identified `outsource-able' package (after make-buy analysis). Similarly, the entire `offshore-able' package may not get offshored. This may not be the most desirable situation, more so when a firm is firm is pursuing GPD for arbitrage reasons. Here system architecture tools like DSM can play an important role. In the study of the five companies, we have shown how DSM could be used to analyze GPD actions. Research opportunities exist to explore and identify measures or constructs to quantify the dependencies between the processes/tasks or sub-systems/components. Such a quantitative approach can help prioritize and optimize GPD efforts for maximum benefits. In the case of Intel, the ratings of A between process required the teams involved in the processes to be co-located. Similarly, in the case of Honeywell, high coordination requirements with tasks constrained to remain onshore did not allow certain tasks to be outsourced. These constructs and measures need to first identify the system architecture approach that the firm needs to follow – process decomposition, or task decomposition, or product decomposition (functional or sectional), etc. The construct and measures identified should correspond to the decomposition route chosen.

The key performance measurement constructs for product development are cost, timing, and quality. The five companies studied pursued GPD for arbitrage (cost, efficiency, resource availability) reasons. However, though each of the companies has looked at arbitrage through cost savings arising out of lower labor costs, they have presented it in different ways. Danaher Motion/Dover identified it as doing incremental engineering work with the same budget, Pitney Bowes as developing strategic partnerships and benefiting from low cost manufacturing, Cessna as meeting all incremental development requirements without increasing onshore headcount, and Honeywell as labor cost savings by outsourcing tasks and differentiating between onshore, medium cost and low cost centers. Arbitrage measurement methods need to be developed to support each such measure that a company may use to justify and proceed on GPD. Such constructs need to carefully consider the trade-offs involved in the case. Research can be undertaken to possibly identify a construct or a limited set of constructs that can be used to evaluate a GPD opportunity. An example could be the Honeywell case, where the lower labor cost of medium cost and low cost offshore locations is offset by increased coordination requirements. A simple mixed-integer programming formulation can be used to determine the locations for the respective tasks, optimizing the trade-off between the reductions in labor costs and the increase in co-ordination costs for moving away from on-shore activities.

Min $\sum_i \sum_j X_{ij} (C_{ij} + L_{ij})$

i : task i = 0 represents tasks hard constraint to stay at base location
i = 1…n represent the tasks that can be done at other locations

j : location j = 1 represents base location
j = 2….k represent other locations

X_{ij} : indicator (decision) variable, = 1 is task i is to be done at location j

L_{ij} : labor cost of doing task i at location j

C_{ij} : coordination cost associated of doing task i at location j

$C_{ij} = C_{ij,0} + \sum_{i'j'} C_{ij,i'j'}$

$C_{ij,0}$: coordination costs between task i at location j and task 0

$C_{ij,i'j'}$: coordination costs between task i at location j with other tasks i' (i' $\neq$ i, 0) located at their respective locations j'

The above formulation incorporates the following assumptions:

- no fixed/setup costs associated with task o/sourcing
- one-time decision (any outsourcing decision is taken once)
- ability to quantify coordination costs
- tasks are completed at only one location (the task is not broken up geographically)

The formulation can be expanded as the above assumptions are relaxed. The relaxing of the assumptions can be incorporated either in the objective function or as constraints. This is a very primary formulation, and clearly research can lead to more sophisticated models that incorporate information flow, dependencies, feedback loops, etc. from the system architecture decompositions to help identify better arbitrage opportunities in GPD.

Earlier in the paper we had discussed the challenges in communication and knowledge transfer that global R&D organizations face. Product development is the transformation of embedded knowledge to embodied knowledge. GPD brings with it the requirements of teams dispersed globally to be able to communicate and comprehend each other. Added to the complexity is the fact that teams could be operating in time zones that do not overlap during working hours. Product development requires constant and consistent communication. As observed in the Honeywell case, the coordination time required between tasks increases when the tasks are done from different locations. Most decompositions stretch to use numerical DSMs to provide a quantification to the level of coordination required, but we have not come across any model that incorporates the cultural differences (and actions required to overcome), communication challenges, or time zone differences, and has tried to incorporate them into a decision framework. Sosa, Eppinger and Rowles (2004) studied the mapping of design interfaces in the product architecture to the communication patterns within the development organization in a firm, and found that strong design interfaces tend to be more likely to be aligned with team interactions. An interesting study could be to observe the change in alignment with GPD – do teams in different locations (with their cultural, communication, time zone challenges) continue to have the same level of interactions or if they change, how do they change, given that their design interfaces remain the same. If they change, is it possible to quantify the change, identify the causes for change, and possibly establish a model to predict the change based on these causes? This study may need to extend across firms.

The above aspects of GPD lead us to consider a key deliverable of any product development process - timing. Most firms manufacturing complex engineered products tend to follow a stage gate process, in some variant of that proposed by Cooper (1993). Assuming that the product definition has been completed, a detailed time plan to launch is laid out. Such a plan does take into account the resource availability. In GPD, these resources may be available, with the added variability of different location, culture, communication methods, and time zone differences. Research studying the changes in project time with GPD could be initiated. They could look at GPD impact on project timing from different perspectives: Does project timing change? If so, by how much? Do firms accept this change in timing or do they, in the event that they are using a location with significantly lower labor costs, hire more personnel to maintain or expedite timing? How does the capability of engineers hired in the GPD location compare with the home base (a measurement construct may need to be developed) and how does that impact project timing? Does a firm incorporate learning and hence expect product development time for the sub-processes/sub-systems offshored to reduce? How are these learnings identified and incorporated in the offshoring decision? How does GPD influence the firm's ability to respond to market changes (leading to changes in product definition)?

In addition to cost and time, the other major product development measurable is quality. Though a firm may pursue GPD for arbitrage, it is unlikely that they may compromise on the quality of the product development process. We observed that Danaher Motion/Dover faced performance problems in their initial GPD effort and had to change their respective offshore suppliers. Similarly, Cessna was not satisfied with the initial progress in their first GPD efforts, though in retrospect they would be willing to work with the same supplier again. Quality dissatisfaction in GPD could arise due to inability of GPD locations to meet home base requirements in terms cost, specifications, timing, etc., communication issues leading to misinterpretation, cultural differences, etc. Considering that GPD efforts are mushrooming now, there are opportunities to research the determinants of good quality in GPD and perhaps help arrive at proper quality parameters which can be used during GPD assessment.

Most of the research ideas above perhaps allude to a single GPD action by the firm. In reality, a firm is likely to start slow, outsource a part of a process or a sub-system, assess the performance, and then decide on how to proceed. It is likely to be a time-phased sequential decision process. In Phase 3 of the Danaher Motion/Dover case, we have tried to outline the possibilities for better utilization of the GDC – the final decision to do so will depend on Dover's satisfaction of the performance of the GDC in Phase 2 and the benefits that the GDC will provide in Phase 3. Similarly, Pitney Bowes, through product decomposition, has been able to outsource the manufacturing of modules. These suppliers may have the capability to progress on to designing the modules hereafter (Canon is already designing the printer technology and the finishing module is a natural step forward for them). Similarly, Cessna will look for higher utilization, through a mix of in-house/outsource, from the GTC. Research opportunities exist here. Real options (Dixit and Pindyck (1995), Luehrman (1997, 1998a, 1998b) looks at capital investment beyond net present value criteria. It works on the principle that the opportunity to invest is an option that may or may not be exercised (have the right but not the obligation). The decision to invest can thus be postponed until favorable conditions exist, either based on arbitrage or other evaluation criteria, but once exercised becomes irreversible. Thus instead of just being positive, the present value of the expected stream of cash from a project must exceed the cost of the project by an amount equal to the value of keeping the investment option alive. By developing a suitable real option structure, researchers can look at how system architecture can progressively identify sub-processes/tasks or sub-systems/components for outsourcing or offshoring. By going in for a sequential approach to GPD, the firm will be able to evaluate the progress until date and the prevailing environment before deciding on the quantum of task/component for the next stage of GPD.

Conclusion

GPD is emerging as the valuable tool for managers. While the first wave of GPD is likely to be a result of arbitrage or adaptation considerations, soon aggregation on regional basis may take over. Though earlier literature has covered multi-national R&D, they have focused more on research. Simultaneous development as envisaged in GPD has received scant attention in literature until Eppinger and Chitkara (2006). We have outlined some of the relevant literature on R&D networks. We have presented five case studies of GPD experiences of companies engaged in complex engineered products. This has helped to identify potential areas of research for academicians and potential points to ponder for practitioners embarking onto GPD. We believe that in the coming years the above will stimulate a fair amount of knowledge creation in GPD.

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