Lifecycle Perspectives on Product Data Management

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ABSTRACT

Implementing a new IT system often requires the enterprise to transform in order to maximally leverage the capabilities generated by the new system. The challenge in using IT as an enabler to change arises from the need to synergistically redesign processes, develop and implement a solution using internal talent and external suppliers, and establish adoption by users. Product Data Management (PDM) technology represents a substantial portion of large industry IT investment over the last decade.. The ability to manage and deliver product data throughout the lifecycle has become increasingly important to the aerospace enterprise as products become more complex, cost and development cycles shorten, and customer, partner, and supplier relationships evolve. Currently, the aerospace community does not have capability to provide traceability from requirements and design through field maintenance. While initially an attempt to understand the application of PDM in product development, what emerged was a study in how PDM affects and enables lean enterprise transformation.

The selection, development, and deployment of PDM solutions were studied in the aerospace industry in order to enable better implementation decisions in varying complex environments. Organizational, technical, and cultural factors were considered as they contribute to a PDM's effectiveness. A current-state observation of nine aerospace company sites highlights the difficulty in reaching the technology's full potential to deliver customer value. Data show that PDMs are being used primarily to manage design engineering data and are not tightly integrated with other business systems. The data also show a distinct difference between prime and supplier companies' spending on and capability of their respective data management systems.

While the value of PDM to product development includes better data quality, traceability and transparency, value to the enterprise is also found beyond the traditional role of PDM. Looking horizontally across the lifecycle and vertically through the hierarchical relationships, PDM provides opportunities for organizational and process change and stakeholder involvement, both important tenets for evolving into a lean enterprise. This conclusion is supported by both the site interviews and the two case studies.

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Chapter 1. Introduction

1.1 *Overview of Thesis*

This research, done in conjunction with the Lean Aerospace Initiative (LAI) consortium, sought to understand the current state of data management within the aerospace industry and the role that Product Data Management (PDM) technology plays in that. Through the many site visits and interviews, a very interesting, informative picture was painted of the efforts that have been made over the last ten years, as well as the thoughts moving forward. Beyond the numbers describing the mechanics of who is doing what and how, there is a story of challenges and invaluable lessons that have been learned along the way.

This thesis is based on interview and survey data collected from nine different aerospace sites and case study data from two of the sites. Under the auspice of LAI, I was able to solicit candid feedback from the companies about their processes, the impact PDM has had in their organization, and the role that users, management, and the corporation play in decision-making. There are many results reported in this thesis that, individually, may only be interesting to those closely tied to the issue. The integral story observed during the research brought unique observations to light as aerospace companies strive for not only success in managing product data, but in enabling the success of their enterprise through those efforts.

1.2 *The Enterprise Impact of IT-Enabled Product Data Management*

The economics of the world have been swiftly changing due to increasing distribution of work. Technology-enabled communication and collaboration has allowed companies to be in multiple places around the world, taking advantage of the best combination of foreign and domestic conditions. As technology has enabled communication and collaboration, it also has allowed an explosion of information and data to be shared almost instantaneously and in large quantities. The combination of these changes, while beneficial in several ways such as reduced costs and better products, has created its share of challenges as well (Deshmukh and Patil 2002; Goh 2003). One of the major challenges for companies that produce hardware and software has been to effectively manage product data: where, when, how, and by whom. Questions are being asked as the need for access to the right data at the right place, right time and right quantity becomes increasingly important.

As an example, here are some questions that follow from "What happens to that product data?"

> Does it get filed into a cabinet? Does it get stored on someone's desktop in building 5-20? How do I know if manufacturing substituted a different part than what is shown on the bill of materials? Who knows where to find a dimension tolerance for part number A-49382 so that field maintenance can repair the part manually? Do I talk to the engineer, or to the manufacturing floor? Then how do I feed information about the damaged part and subsequent maintenance back into the system?

These questions are examples of what arise throughout the product lifecycle, illustrated in Figure 1. Customer requirements are flowed down and transformed into designed parts and assemblies, which are then passed to those in manufacturing. There, build-to plans are designed, the parts are built and delivered to the customer, and in many cases, are maintained by, or at least have maintenance instructions and information provided by the original equipment manufacturer. Technology enables the quick and accurate ability to share and archive data for use by another function or as a reference later on, as well as a workflow that facilitates the prescribed flow of the data.

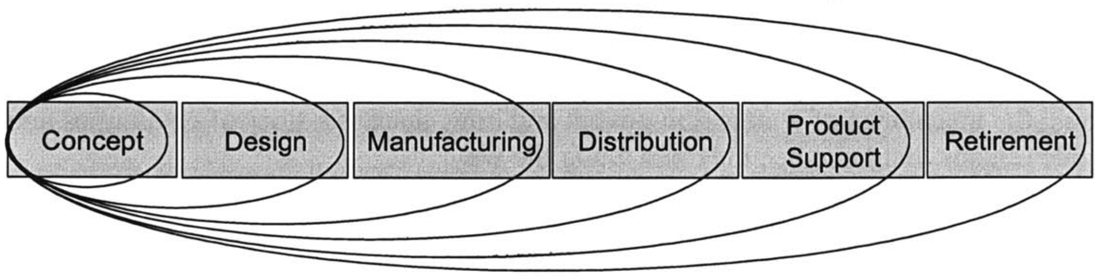

Figure 1: The product lifecycle from concept to retirement.

The difficulty is that many organizations, both small and large, have several technologies and tools within their organization that are not integrated with one another, and in many cases, outdated (Aziz et al. 2004; Orlikowski 2001).

1.2.1 Value Proposition of Data Management

The extended enterprise includes all of the organizations within a company, including functional disciplines and any centers geographically removed that have some role in the lifecycle of a product. It also includes the supply chain network and the customers. The way in which data are managed across the extended enterprise impacts the ability to provide value to all stakeholders. IT solutions that are enabled to serve a purpose effectively at the enterprise level have the potential to help companies provide that value.

Figure 2 demonstrates the amount of overlap that exists between what we think of as traditional functional divisions and their associated data. There are only a few pieces of data created in one place that are not used directly or referenced in others. A majority of traditional product data is created and owned by the engineering organization. However, data is created at every step of the process, and is typically required to be traceable, even if not used directly at a later point. For all the data used downstream, having the data well documented and easy to find is essential. If, for example, the product support organization only needed data created or modified from the manufacturing floor, then a single tool that interfaced the two groups would be sufficient. In the past, and currently in many cases, this would be the situation. Product support, however, relies on manufacturing data, as well as engineering data, cost and schedule data, and supplier data. Supporting a unique tool for each link creates more complexity in the ability to provide data flows throughout the organization (Orlikowski 2001) The challenge of maintaining the links and sustaining seamless management of data is near impossible.

	CONCEPT	DESIGN	MANU-FACTURING	PRODUCT SUPPORT	RETIREMENT
Data Created	Requirements Schedule	CAD/Drawings EBOM Structural Analysis Engineering Notes Schedules	MBOM ABOM Tooling Models Non-conformance Schedules Quality	Maintenance Field Schedules Tech Pubs	Close-out
Data Creator/ Owner	PM R&D	Chief Engineers Cognizant Engineers Designers Analysts	MEs Shop floor PM	Product Support	PM Customer
Data User	R&D IPTs Designers PM	Designers Analysts MEs PM Customers Suppliers	MEs Engineering (Non-conformance) PM Customer Supplier	Product Support PM Customer Suppliers	Customer
Data Storage	DOORS HG	PDM ERP EDS Native Vault HG	PDM ERP MRP MRM Native HG Paper	PDM ERP HG Paper	PDM ERP HG Paper

PM = Program Management MEs = Manufacturing Engineers

HG = Homegrown IPTs = Integrated Product Teams

Figure 2: Where data is created in the life cycle is, in general, not the only place it is applied or built upon.

What enables the engineering organization to design a product such that it can be easily manufactured and supported? There is an absolutely essential downstream use of data, as well as feedback opportunities to better enable iterative activities. If the design organization has access to the records from product support and can see trends in maintenance and repairs, it can avoid making past mistakes that caused re-design in the last product development cycle. There is also the opportunity to re-use designs or parts that were previously created, saving time spent on designing and testing. The importance of feedback loops to the upstream product development process has been studied and documented (Stanke and Murman 2002). Information, if used properly, has the potential to increase learning and knowledge in the process.

Beyond the flow of traditional product data, there are additional data that the organizations use that they do not necessarily create. An example of this is schedule data, which might be created and controlled by program management or procurement for example. The decision of how these additional data are managed and shared becomes integral to the design of the IT infrastructure.

The ability of an enterprise to seamlessly manage product data across the lifecycle provides benefits at every interface along the way. In order to achieve these benefits, there is always a need to have unobstructed access to the right data at the right place and time. There are several avenues to be exploited.

- Storing and locating old data allows for reuse of information or parts. This, minimally, reduces the need to search endlessly for data and the need for product rework in many cases.
- Having a seamless flow of information reduces wasted time. This applies to both internal functions such as engineering and manufacturing, and external interfaces such as a supplier or customer.
- Automating workflows provides gains in design or rework cycle times.
- Having a single tool to manage data across the lifecycle reduces IT maintenance and overhead costs.
- Being able to provide data to a supplier or customer digitally increases manufacturing efficiency and reduces costs due to paper processes.
- Providing a customer electronic data access and transparency to a project provides a competitive advantage.
- Finally, the ability to track downstream data affects safety, as well as provides better estimates for future work on budgets, timing, etc.

It is evident that the ability to manage data effectively can create major impacts on the ability of an enterprise to provide value. It has only been recently, however, that many of these value-added capabilities became available at the enterprise level. As IT and the complexity of products, processes, and the relevant organizations have advanced, coordination of the many components has become increasingly critical and difficult at the same time.

1.3 *History of Design Data*

There have been major changes over the last two decades regarding how engineering drawings, models, and other data are created. If we take drawings as an illustrative example, they were drawn on paper by hand just twenty years ago. Three perspectives were drawn each with dimensions and notations about the manufacturing process or material specifications, and the shop floor would then develop the manufacturing plans separately on paper. If a mistake was found or a change to the design occurred during the process, the affected drawings would be modified for a minor change (known as red-lining) with the engineering change notice attached to the drawings, or for major changes (or approximately five minor changes) a new drawing would be created. As computer-aided drafting (CAD) and design tools became available, it became easier to make changes to a drawing. People also were able to create more complex drawings because the tools allowed for better management and manipulation of the complex designs.

CAD technology evolved from wire-frame to two-dimensional, and recently has made the jump to three-dimensional and parametric modeling capability. As more parts are created and higher volumes of changes are made, resulting in the creation of more data, the need to manage these data more effectively and efficiently has increased dramatically. Similar evolutions of technology have occurred in analysis, manufacturing and support systems. Although we should theoretically be accomplishing greater things with greater speed and accuracy, the increased production of data has overwhelmed traditional data-handling technologies and processes, making the ability to store, locate, and utilize the data increasingly difficult.

The explosion in volume of product and enterprise data (budgets, schedules, customer and supply chain management/relations, etc.) has created a vast market of information technology solutions. Beyond the design and analysis tools, there are higher-level products, such as Enterprise Resource Planning (ERP) and Product Data (Lifecycle) Management (PDM/PLM) solutions. New technologies, promising to revolutionize the way information enables a business, have evolved a great deal over time based on lessons and experience taken from industry. For example, the type of information that is managed, how it is managed across interfaces, and who owns it, are critical nodes where changes have occurred as the need for data management across the product lifecycle has become more apparent.

Based on advances in product data-related IT, companies have been empowered to create higher-fidelity drawings, to manufacture parts more accurately and with greater speed (Deshmukh and Patil 2002; Abramovici and Sieg 2002), and to have more opportunities in monitoring and measuring what takes place during a product's lifecycle. This brings us back to the burning question: Why have so few companies been successful in gaining the benefits described from their investment?

1.4 *IT Capability Misconceptions*

It is tempting to associate an "IT solution" with sending out the IT organization to find the latest software that claims to fix your problem. From there, companies have often paid a consultant to help launch the software without giving much consideration to the organization's design and processes. When applying specific technology within a functional organization, this may be an appropriate approach. Historically, IT solutions have been developed for every functional process that could possibly be automated to meet specific functional needs, such as advances in CAD tools for design engineers. As solutions became cheaper, the barrier to invest in them fell, and functions began architecting their own, individual IT solution. When IT began addressing cross-functional processes, the implementation mentality was not revisited and the application of progressively cross-functional tools to individual functions remained unchecked. This has resulted in technology-driven IT implementations as seen in the aerospace industry. As the IT tools continue to evolve, the approaches, mindsets, and expectations of them appear to remain dangerously unchanged.

There is a similar parallel in how institutionalized IT has evolved within organizations. Historically, companies implemented their own IT, usually in an ad-hoc fashion. The design team would be responsible and given the authority to select and purchase the technology that helped them do their job. The analysis team was allowed to do the same, and so on. As technology changes became more rapid and organizations began to disperse geographically, companies saw the need to centralize the IT efforts taking place internally. Many companies responded by institutionalizing a formal IT department within the organization. Unfortunately, many of the individual efforts continued at the functional level. The shortfall in not addressing the organization with the IT infrastructure design becomes apparent when tools are selected and implemented that do not adequately address cross-functional needs.

1.4.1 Thinking Outside the Silo

As companies invest in enterprise IT solutions, there needs to be a guiding *enterprise* view. To successfully address the enterprise, the processes and internal and external interfaces must be addressed. The current state of the enterprise can fundamentally be defined by its processes and interfaces. The culture and technological infrastructure are examples of an enterprise's characteristics, but knowing its processes presents a fundamental understanding of how the enterprise operates (Hammer 1999).

Although "re-engineering" has recently been a word on the tip of many managers' tongues, most organizations are not prepared to actually go through an enterprise transformation. Learning, analyzing, and altering an enterprise's processes is a daunting challenge that cannot be met without also addressing the culture and infrastructure of the organization.

1.4.2 The Technology Vendor's Role

As IT solution vendors try to meet the challenges of managing data across different companies, they are faced with organizations steeped in traditional cultures and processes. The needs of even seemingly similar industries, such as automotive and aerospace, still have fundamental differences in their business rules, requirements, and lifecycles that necessitate differences in their respective technological solutions. Most major business tools are being used across multiple industries that have very different needs.

The fallout seems to be that the vendors try to sell their solution and then make it work for the specific organization. Working groups composed of industry representatives have been trying to steer the vendor's in the most useful direction based on their needs and desires.

1.5 *Policy Implications of Data Management*

There are two fundamental threads that frame the policy discussion regarding data management IT implementations. The first thread is organizational and is two-fold. First, by whom and where in the organization is the technology valued. This influences the effectiveness of the technology, which in turn directly impacts the value derived from the investment of resources: people, time, and money. The second is in understanding and adapting the ownership of data within the organization. The extension of this to the extended enterprise increases the complexity of the statement. If an organization is able to define and track who owns and manages data internally, this does not guarantee that the external stakeholders are going to agree, or be able to align their processes similarly.

As these choices trickle down into the different lines of businesses and heritages, the reality of the tool adoption is much different than the expectation. In many cases, based on the research findings, companies have not done a thorough job of surveying what is happening at different levels within the organization to understand the maturity, or lack thereof in their current tool implementations and what are the different needs. They also, in setting a corporate mandate, consider the gain to the enterprise over the loss to individual parts of the organization, but they do not set forth plans to make those changes successfully.

The second thread has more to do with the PDM-related technology market and its drivers. Many large corporations have made corporate-level decisions regarding standard business tools including PDM. In aerospace, it has been part of an effort to standardize processes and tools across the organization. The Air Force has done a similar thing, prescribing a specific PDM tool to be used for all of its applications. How have these large contracts affected competition within the market? What have been factors influencing the tools chosen by corporations and the government?

Smaller supplier companies are trying to make similar decisions for their own needs but now they may have several different customers calling for different tool compatibilities in an effort to standardize tools. Should the tools they buy into be dictated by their customer, or is there a better way to enable interfacing across the extended enterprise for suppliers that have multiple customers?

1.6 *Data Management in Aerospace*

The aerospace and automotive industries are often referred to together due to similar industry histories and products. It is important to mention here because they are the largest users of PDM/PLM technologies in the U.S. and have had a large part in shaping the technology (AS 2003). The aerospace industry was the initiator of rudimentary PDM capability, but as software vendors began filling the gap with COTS products and the technology improved, the automotive industry became a bigger investor in the technology (AWST 2003). As reasonably expected, the software evolved over time to be more suitable to the automotive industry's product structure and processes. When aerospace companies started investing again, they found that the software had major shortcomings and it was like trying to fit a square solution into a circle.

Both industries tend to be functionally compartmented or "silo-centric" meaning that the engineering does its own thing separate and apart from the manufacturing and so on. Although there have been organizational attempts to fix this such as concurrent engineering and integrated product teams (IPTs), internal interfaces still tend to be treated the same way by the organization. They also have both struggled in updating decade-old processes across the enterprise. This is surprising considering the advanced technology often associated with their products, especially for aerospace companies.

Another similarity between the aerospace and automotive industries is the type of external interfaces that must be managed. Supply chain networks, although some consolidation has occurred in the past, are still complex relationships that easily can become management challenges. The communication of requirements and scheduling is critical to meeting schedule and budget constraints on any project. Effectively interfacing with the customer is also critical, especially when there are multiple customers with different requirements.

Table 1: A comparison of aerospace and automotive industry characteristics.

Differences	**Automotive**	**Aerospace**
Product	Core design with variants; high output	Specialized product; low output
Lifecycle	Concept – Design – Manufacturing – Distribution Fast Clockspeed	Concept – Design – Manufacturing – Product Support – Retirement Slow Clockspeed
Customer	Commercial, some Military	Military/Government, Commercial
Supplier Network	Complex network; low-margin, high-volume output	Highly complex; high-margin, low-volume output
Similarities		
Industry	Mature, Consolidated	Mature, Consolidated
Product Data	Heavy in CAD/drawing management; manufacturing	Heavy in CAD/drawing management; manufacturing
Complexity	Mid to High	High

There are also some ways in which the aerospace industry is unique. Aerospace products tend to have very slow clockspeeds when compared to any other industry, especially that of electronics. A typical lifecycle for a military aircraft may be up to 40 years, or 20 for a spacecraft. The requirements for data retention are also more of a burden, lasting, in some cases, up to 99 years after retirement of the product (on the space shuttle main engine, for example). Production runs for aerospace are also much smaller than most, only producing a few to a couple hundred deliverables a year, as opposed to 200,000 of a given automobile model. Aerospace products also tend to be more complex in general, the epitome of a systems engineering project, due to the numerous structural, power, communications, life-support, and software systems that have to be integrated successfully.

From the comparison of the automotive and aerospace industries, it is easy to see how they would be heavily invested in PDM technology, but the same solution would not meet both of their needs.

1.6.1 Ideal State

Ideally, product data would be managed in such a way that no errors in the data are present; information handoffs between functional organizations, off-site locations, suppliers, and customers are seamless and transparent; and it is easy at any given time to find any piece of information. Given the state of technology today, everyone could have the ability to share data digitally, and not have to support a paper process in parallel or make concessions for one. Successful data management is not the ability to provide any information, any time, anywhere. More important, it is to provide the *right* information at the right time and place.

1.6.2 Current State

Currently, in the aerospace industry, there are some companies that devote an entire department to the tracking of product data. There is such an abundance of legacy data in disparate locations that finding any single piece of product data can be impractical. In cases where the original can not be found, duplicate product data has to be created. When the old data surfaces, program managers have to explain to the customer why there are two versions of a part drawing, and why they look different. In another case, a supplier will start working on a part not realizing that an engineering change is either in process or approved. This causes rework and delays, which cost the program time and money.

Most aerospace companies today also continue to support paper processes internally due to supplier needs or customer requirements. Even if they have invested in digital technology, usually their company culture has hindered retiring the use of paper. Many suppliers have not made similar investments and continue to need data provided to them in legacy forms. Using paper introduces a need to scan in drawings or documents, instead of having them initially created as a digital record. It also represents a continued use of an old process that hinders the organization from fully moving into new processes.

Finally, several companies within the aerospace arena have researched and invested in product data management infrastructure. A number of them have made progress in storing and managing their product data from a single source and automating certain processes. However, it is apparent through this research that the progress for product data management thus far has largely been limited to the design engineering process. Data created and managed within design engineering is not being shared, reconciled with, or added to as effectively as it could be, as the product evolves downstream. These shortcomings in both the technology and the processes limit the enterprise and its stakeholders from gaining real value.

1.6.3 Challenges in Aerospace

The challenges of data management present in the aerospace industry are particularly difficult. The timely inefficiencies of finding and sharing data, costs of transferring data, and risk introduced by not tightly controlling increasingly complex data makes it difficult to manage and assess costs. There are considerable rewards to be gained by successfully implementing a good data management solution. In order to present a comprehensive solution to the enterprise, there are many factors to consider, each of which presents its own challenges.

As noted previously, one of the most important steps in implementing an enterprise solution is to address the underlying processes. Without defining and understanding the processes it can not be expected that the tool chosen will enable those processes, let alone support them. There are examples where a technology solution is put in place without consideration of the processes. This inevitably leads to a less successful solution and dissatisfaction within the user community.

While redefining and implementing new processes, there are several additional challenges with such projects. Although processes are most often overlooked, culture seems to be the biggest barrier. People will often do whatever they can to keep their familiar systems and processes. Dickson and Simmons identified three categories of cultural resistance: aggression, a physical or nonphysical attack on the information system; projection, where the user blames the system; and avoidance, which includes withdrawing from or avoiding interaction with the system, often as a result of frustration (Senn 1978). It is difficult to pull information from the users, successfully train them at the right time, and communicate the impact of what is going to take place. There is also the challenge of selecting the right technology solution, or at least, the best one. Working with software vendors to meet an organization's needs requires constant communication and negotiation. Finally, in all examples studied in this research, there were unexpected occurrences that often caused a major change in the implementation. The inability to foresee challenges can and has caused many implementations to be unsuccessful.

Given the current state of data management within the industry, the decision to implement a PDM solution provides an enormous opportunity to the enterprise. If chosen and integrated within the enterprise infrastructure poorly, PDM can introduce waste to the system through data errors, poorly designed processes, and ineffective interfaces. Any savings expected based on the time, energy, and money invested in the solution go unrealized and are lost. If chosen and integrated well, PDM provides an opportunity to do more than capture design data. It can enable an organization to execute lean principles that are critical to stakeholder value.

1.7 *Research Questions*

At the outset of this research, several major questions were posed out of which the key research questions evolved. These have guided the research in addressing the practical needs of the industry as well as understanding the phenomenon taking place. They have also set context appropriate for addressing many of the underlying questions that have been provoked through the research. The questions are discussed in detail below.

What are companies' high-level requirements for PDM and how are those implemented?

This question addresses the core of both what is desired and is being accomplished in the industry through PDM. The requirements are sometimes technical, but also address enterprise needs for a system. They affect the approach used in orchestrating a solution because they identify the absolute needs from a level above engineering. Understanding the way in which requirements are implemented leads to lessons about how organizations typically plan to operationalize a solution, and then what actually occurs.

The second question is:

What are the success factors in implementing PDM with programs at various levels of maturity?

The companies that participated in the research had development programs that ranged from less than a few years old, to more than 20 years. They had varying levels of both PDM technologies in place and lean practices instituted within the organization (Shaw et al. 2004). There also was a divergence in the amount of experience each company had with PDMs and similar tools. A few had legacy and homegrown PDMs, which helped them understand the technology quickly but limited their thinking of what were the possibilities. Others were implementing PDM for the first time and struggled from lack of implementation experience.

The third question is:

How does PDM support lean integration on an enterprise scale?

This addresses the value proposition of PDM. A lean philosophy has been advocated and practiced for some time in the aerospace industry. Although many have institutionalized lean principles, they still are not able to take full advantage of the benefits. Speaking to the challenges stated above, the organization is a barrier to a complete adoption of lean. It is the view of this writer that lean principles and practices should continue to be promoted in ways that have positive impacts on the organization. I also believe that an opportunity to address some of the organizational barriers and continue to transform the enterprise is found within PDM and its implementation. Product data spans all parts of the lifecycle, and therefore must cross interfaces, both internal and external to the prime organization. Integrating seamless information flow, especially of product data, throughout the lifecycle implies that there is integration across the enterprise.

Beyond these three key questions, there also have been emergent findings that were not expected from the research.

1.8 *Thesis Outline*

Following the Chapter 1 introduction, a review of literature is presented covering briefly the concepts of Lean and product development, as well as data management, IT and how it relates to firm value, organizational change considerations, and the evolution of PDM technology. Chapter three begins to describe the research by providing the link between the literature review and the development of the research agenda while Chapter four explains in detail the resulting methodology used and how it was determined. Chapter five presents the individual results based largely on the interview data with some case study results when appropriate.

Chapter six contains the two case studies, spotlighting the experiences of two very different aerospace companies and the role PDM technology plays in their company. The case studies describe their journey from the first day PDM was selected as a business solution. Chapter seven pulls together the big picture, walking through the conclusions of the research and the work that is left to be done. The interview and survey tools as well as the case study protocol developed for this research can be found in the appendices.

Chapter 2. Literature Review

2.1 *Lean Product Development*

The concept of Lean has slowly worked its way from the foundations of its application on the manufacturing floor to an evolved philosophy that finds itself being applied at the enterprise level. Starting with the Toyota Production System, Lean emerged as a reduction in wasteful activities such as repetitive or unnecessary process steps and handoffs, mistakes and rework, and waiting (Womack and Jones 1996; Clark and Fujimoto 1991). Due its success in the automotive industry and the similarities between automotive and aerospace manufacturing, the notion of applying lean to the aerospace industry quickly gained momentum.

Aerospace companies are continually under more pressure to perform more efficiently and address ever-narrower customer segments (Holman 2003). The increasing complexity of its products and organizational boundaries due to globally-dispersed "enterprise" teams has made efficient product development more difficult. The decline in defense spending has put the pressure on enterprises to decrease the costs of manufacturing, operations, and maintenance to the products.

As recorded by Rother and Shook in Learning to See, the accomplishments of lean in manufacturing became mature through research and application into the late 1990s. The Lean Aerospace Initiative (LAI), a research consortium consisting of military, academia, and aerospace industry members, built on the work that had been done in manufacturing, and has helped expand lean application more broadly in the aerospace industry. LAI pushed the envelope, moving into a more value-centric focus of lean that reached beyond manufacturing and into other parts of the product lifecycle.

In 2001, LAI associates published Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, a book highlighting the value of lean and where it stands from a research perspective. It also shares what LAI has learned over the years through research with its consortium partners. Becoming lean is defined as "a process of eliminating waste with the goal of creating value," an important distinction from the common "labor reduction" mentality that many associate with lean (Murman et al. 2001). With the goal of transforming stale business mindsets and processes, the research continues at LAI to look at how lean can be applied and measured at the enterprise level (Murman et al. 2001). As Stanke notes in a paper describing a lifecycle value framework, "At an enterprise level, creating value for all stakeholders requires considering the entire lifecycle." (Stanke 2002) Although the benefits of propagating a lean philosophy throughout an enterprise have been explored and theoretically make sense, the actual number of successful "transformations" and the benefits achieved at this point have largely been short-sighted. As illustrated in the LEV book, "Islands of success" have been the limit for many due to barriers such as their size, organizational and technical complexity, and culture.

Both product development and product operations and maintenance have recently been areas ripe for lean research. It is often cited that 80% of a product's lifecycle cost is committed during the first 20% of the lifecycle (Anderson Consulting), stating the impact of decisions made during the product development portion of the lifecycle. Research by Huie in 1980 showed that for a typical aircraft project over a 15 year period, 55% of its lifecycle cost was for operations and support, highlighting the importance of considering downstream implications of the lifecycle (Stanke 2002) as well. Many of the directives from the Air Force have desired product support research in trying to make their products more affordable. Unlike the historical success in manufacturing where measuring parts and inventories for benchmarking was more quantitative, measuring process-driven lifecycle phases has proven more difficult.

Product development, similarly, is an information-driven process, rather than a series of tangible tasks. Research on the definition and understanding of product development has been done by Chase and Slack while Tyson Browning looked at modeling cost, schedule, and performance in complex system product development. Many others have looked at how to transfer the identified "waste" found in manufacturing to its parallel in product development. As characterized by Holman "Just as wastage is a key metric in lean manufacturing, information wastage is important in gauging the efficiency of information-driven product development." (Holman, 2003) Other contributions have been made by McManus and Millard, Bauch, and Kato in identifying waste indicators and measuring them (see Table 2) for their relative effect, but challenges such as quantifying iterations or defining when rework counts as waste has slowed down its success. Ongoing research is currently being spearheaded by LAI research staff on addressing areas of waste in the product development process and determining how best to measure those wastes and make improvements.

Table 2: Waste indicators and their definition as reported by McManus and Millard (2002).

	Waste	Description
1	Overproduction	too much detail, unnecessary information, redundant development, over-dissemination, pushing rather than pulling data
2	Transportation	information incompatibility, communication failure, multiple sources, security issues
3	Waiting	information created too early or unavailable, late delivery, suspect quality
4	Processing	unnecessary serial effort, too many iterations, unnessary data conversions, excessive verifcation, unclear criteria
5	Inventory	too much information, poor configuration management, complicated retrieval
6	Unnecessary Movement	required manual intervention, lack of direct access, information pushed to wrong sources, formatting
7	Defective Product	lacking quality, conversion errors, incomplete, ambiguous, or inaccurate information, lacking required tests/verification

Waiting and inaccurate or inappropriate data being delivered are examples of product development waste that could potentially be lessened or eliminated through successful workflow and data management. Millard defines seven heuristics to make product development leaner, such as creating a continuous flow of information. Arguably, each of the seven suggestions could be served in some way by a successfully implemented and integrated PDM solution (Millard, 2001). The capabilities provided by a PDM just within product development have far reaching implications in driving product development to a more lean state.

Research has looked at different pieces of the product development process and the use of different methods to create and share data. In 1998, Hoehren examined the use of engineering drawings as an indexical medium and found that their use was related to avoiding late engineering changes (Carlile 2002). Literature reported by Zahay et al. found that "inappropriate, irrelevant, or unimportant technical documentation distribution contributed to poor communication between scientists and engineers, and that it ultimately resulted in failed projects."(2003) Engineering changes which typically occur throughout the lifecycle affect not only the product but also the documentation. Defense aircraft research found that two of the four dominant causes for engineering changes were design assumptions made in the initial phases and the need to correct design or product deficiencies (Hsu 1999).

Carlile and Lucas's review of product development literature links the success of product development teams to their ability to communicate across cross-functional boundaries. They also cite Brown and Eisenhart's review showing that team communications and boundary spanning are two of the most critical issues in the product development success (1995). Carlile and Lucas's work focused on boundary objects – information-rich representations of the information being communicated such as an engineering drawing or a prototype – and how they affected the ability to communicate. They found that "boundary activities that establish greater representational complexity had an increasingly positive impact on team performance...because they provide more adequate representational capacity to support the cross-functional work of technology development teams." Carlile attributed part of this to those within specialized domains having the ability to better understand and assess new knowledge as well as negotiate alternatives through using the boundary objects (Carlile et al. 2002). These findings bring us to a question: what is the quality of the data being used to perform such activities?

2.2 *Product Data Management Technology*

PDM technology has rapidly evolved over the last few decades as its desired functionality and prevalence in demanding product development companies has increased. The historical roots of PDM started with computer-aided design (CAD) data management. Initially a vaulting capability, homegrown systems were developed by aerospace and automotive companies that needed a way to manage multiple parts and versions of CAD files. Vendors began developing management systems to work with their proprietary CAD tools, but the impact of CAD-related data management was felt only within the design process.

The PDM technology that followed improved upon the vault by having the ability to implement workflows, automating the data handoffs that occur during a process. This provided the potential to enable better design data flow across not just product development, but the enterprise. The current technology, as it has matured, is marketed to perform approximately seven, now seemingly basic, functions: data vaulting, document management, release and change management, product structure, viewing and mark-up, classification and retrieval, and configuration management (as reported by Abramovici et al. 2003).

As described by Gould, PDMs bring inherent shortcomings when looking at data management and flow from an enterprise perspective. PDM was developed to solve the problem of managing CAD files, which created a great BOM that was then thrown over the wall to a commercial business system for manufacturing purposes (Gould 2002).

As PDM has evolved on its own, and grown into new concepts such as Product Lifecycle Management (PLM), its potential impact has grown beyond product development. It now encompasses both evolutionary change involving work flow improvements during the design phase and revolutionary change through integration of design and manufacturing processes.

CIMdata defines PLM, from the perspective of a provider of PDM technology, as "a strategic business approach that applies a consistent set of business solutions in support of the use of product definition information across an extended enterprise from concept to end of life – integrating people, process, business systems, and information" (CIMdata 2003). PLM as it is currently defined requires revolutionary change to enable the seamless flow of product data across the entire lifecycle from design, all the way through product retirement. The conceptual mapping of the evolution of PLM to the levels of enterprise transformation is shown in Figure 3. The figure follows the Venkataraman framework for the enterprise reconfiguration that happens when IT systems are adopted (VM 1994).

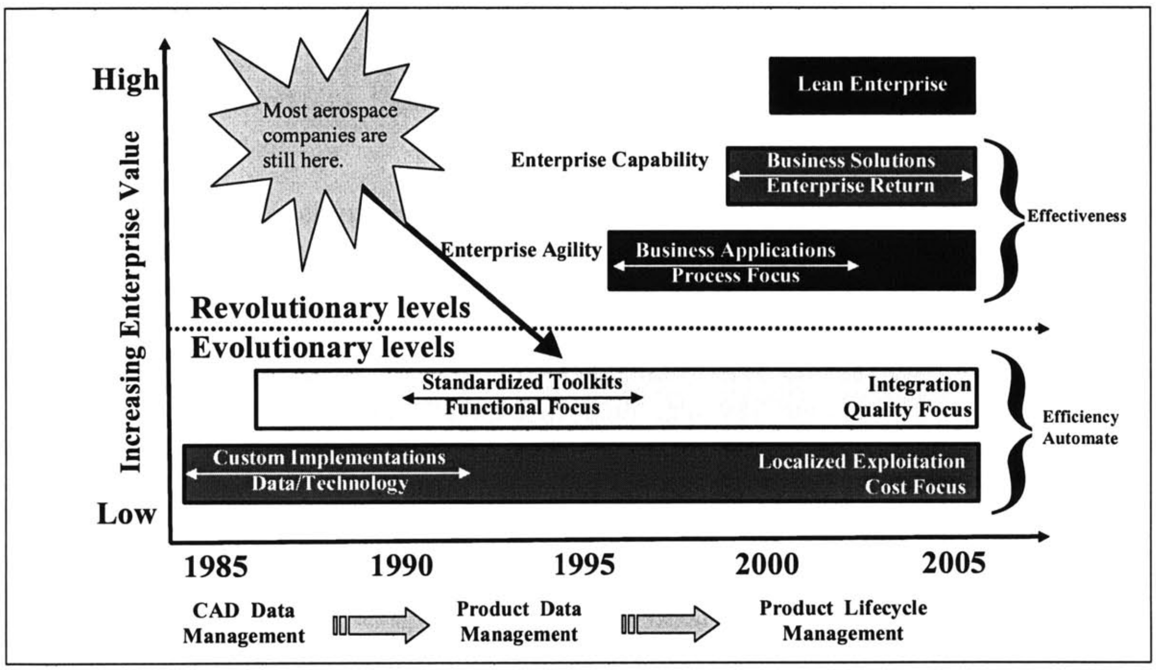

Figure 3: PDM in the context of enterprise transformation (Hines and Srinivasan, 2005).

There has been significant research into data management and its associated technologies. Many publications provide an overview of the evolution of PDM/PLM, (AS 2001; Hameri and Nihtila 1998) some of which forecasts how the technology is evolving or suggest how it should be evolving (Datamation 2005). Others have researched different architectures and approaches including a federated architecture (Chadha), a product versus process approach to data properties for enhanced coupling and transparency between the PDM and other systems (Weber et al. 2003), and state of the art trends in specified product sectors (Abramovici et al. 2003). Mesihovic et al. provide a review of current shortfalls in PDM such as lack of STEP-like standards and integration with software configuration management applications (2004).

There are also many publications describing the benefits to be gained through product data management such as shortening the design engineering cycle and enabling reusability, but few provide actual data where this has occurred and to what degree success has been obtained

(Deshmukh and Patil 2002; Datamation 2005; CIMdata 2002; AWST 2004). A CIMdata study reports that only 5% or so of employees that need CAD data actually have access to it, making the ability to integrate and flow data critical to the effectiveness of an engineering organization (MacKrell and Miller 2005).

An AMR report cited in Aviation Week and Space Technology stated that the aerospace industry spends more on IT technology than any other industry (Hughes 2003). The investment in PDM technology specifically has been most intensive in the automotive and aerospace industries, with a swing back and forth between the two over the last 10 years (Geiger 2001; Hughes 2003). As automotive investments overtook those of aerospace, the technology development began to resemble more of the automotive processes (Hughes 2003; AS 2003). Only recently has aerospace investment begun to increase again, and companies are struggling with finding a suitable technology for their business processes.

There has been little research highlighting the current state of PDM/PLM within the aerospace industry. The aerospace industry has some unique features about it that make data management and IT adoptions particularly hard. These include:

- Long product lifecycles (up to 90+ years) where sustainment is often carried out by non-original equipment manufacturers specializing in sustainment activities
- Required customer and/or government agency visibility throughout the product lifecycle
- Multiple complex products being conceptualized, designed, and built by multi-national partnerships with varying levels of process sophistication and capability.

The ability to communicate engineering across interfaces and boundaries is challenging given the complexity of systems being designed and the additional difficulty in communication when teams are not co-located. As product complexity increases, both geometrically and by the number of parts, the precision needed in managing the data also increases (Datamation 2005) as well as the amount of data being created (MM 2005). Based on knowledge developed regarding the downstream implications of upstream actions, accurate and timely communication of data is critical. The question of what impediments are faced during implementation of a product data management system has been asked, but how they were overcome in the successful cases has remained an open question.

2.3 *Finding Value in Information Technology Implementations*

The contribution of IT to firm performance and what makes IT a successful investment has been studied outside of the aerospace and defense community in varying ways and with mixed results. It is widely documented that billions of dollars are spent every year by companies on IT and IS systems with very little return, either in savings or otherwise, to show for it. A realization to be made is that as the environment that companies are operating in globalizes, more and more organizations are being forced to operate as "virtual enterprises." The requirements that enable these organizations to operate have also changed (DP 2002). Aziz et al. provide a literature review of work done to develop frameworks for virtual enterprises that try to provide collaborative capabilities (Aziz et al. 2004).

Hunter's literature review on the link between IT investments and firm performance includes the firm's ability to manage and utilize IT, the training and organizational transformation that accompanies the IT, and the characteristics of the organizational tasks, processes, and functions to which IT is applied. Hunter found that in the retailing industry, IT investments negatively impacted the firm's market value, but attributed this to the industry context (concentration, declining profitability, and single-firm dominated) at the time. Chatterjee, Richardson, and Zmud found positive returns to IT investments under "transformational" industry conditions (Hunter 2003).

Bharadwaj's review notes that anecdotal evidence and case studies indicate that effective and efficient use of IT is a key factor differentiating successful firms from their less successful counterparts. Sambamurthy and Zmud found that the managerial ability to coordinate the various activities associated with the successful implementation of IT systems was a key distinguishing factor of successful firms (Bharadwaj 1999). Many studies have offered mixed results of the relationship between IT investments and actual firm profitability, which have been questioned on methodological grounds. Other researchers have argued that IT investments which are easily duplicated by competitors do not necessarily provide sustained advantages. It requires strategic leveraging of the IT to deliver competitive advantage and determine a firm's overall effectiveness (Bharadwaj 1999).

Bharadwaj concluded that IT-resources in and of themselves are not sufficient to enable strong IT performance. Despite large investments in IT, not all firms are successful in creating an "effective enterprise-wide IT capability to leverage technology to differentiate from competition".

A report was published by the Government Electronics and Information Technology Association (GEIA) in 2004 aimed at establishing the level that lean principles and practices as defined by LAI had permeated the US aerospace and defense industry. A principal finding of the research was that strategic implementation of the two major classes of enterprise-wide IT, ERP and PDM systems, was fundamentally linked to the success of Lean programs (Shaw 2004). Enabling data management practices, such as maintaining a single bill of material as supposed to several, aided in leaning out affected processes. Value of the enterprise IT systems was also based on their ability to implement and sustain business process changes determined through lean activities such as value stream mapping, as well as track and capture process metrics more readily.

2.4 *Challenges in Implementing IT*

Challenges or poor practices and decisions that have been observed in industry are often recorded in an attempt to understand either why implementations completely fail, or why they do not deliver financial returns as expected (Boynton 1994). The contributing factors cover a range of context including organizational, technical, and managerial factors (Goodhue, 1988). In 1978, Ballou highlighted the importance of management's role; he established a framework for cultural resistance; and he stated that the economic evaluation of information systems relied on cost displacement while ignoring the intangible benefits. Ballou also indicated that matching IT decisions with the organization and data management strategy was very important. Almost 30 years later, we see similar patterns in these failed IT implementations. So what makes it so difficult?

2.4.1 Technological Challenges

The technology challenges faced by enterprise information system developers ranges from understanding legacy and novel systems and applications, the type of data being managed, and the relationships of those data. Goodhue offers a list of challenges based on his work looking at 20 diverse firms and their data management efforts. From a technology standpoint, he identifies the difficulty due to resident or legacy data systems and orientations in place that require changes toward standardization in order to meet new needs (Goodhue et al 1988). Others have noted that there is often a lack of knowledge of the tools being purchased and of the enterprises the tools are being designed for (Werner). There are at least eleven companies developing and marketing PDM/PLM technologies, indicating that knowledge of both the specific tool and its applicability to the enterprise could prove to be challenging (Bonasia 2004). As a lot of the literature specifically about PDM-type applications will point out, there are many opinions on how data management systems should be architected in order to provide the desired outcomes of seamless information flow and integration of systems and organizations (Chadha; Datamation Jan 2005; Deshmukh 2002).

2.4.2 Organizational Challenges in the Context of Technology

Similar to that of IT, there is a plethora of literature on organizational change in and of itself and the challenges associated with it. Understanding how a culture or organization rejects, embraces, or adopts technological change is crucial to developing a successful implementation plan for any new IT effort. Based on the number of IT failures in organizations, the question of why is of interest. An article written by Gene Blouin from Life Cycle Solutions, Inc. seeks to provide organizations with a checklist to determine if they are organizationally prepared for a PDM implementation (Blouin 2004). The checklist has seven key indicators including financial preparedness, a sincere understanding of the impending changes, and competitive quality regarding the current infrastructure of the organization.

There is an area of literature regarding the intersection of technology and organizations. In 1998, Markus identified three conceptual groupings regarding the literature on information technology and organizational change: the technological imperative, the organizational imperative and the emergent perspective. "In the technological imperative, information technology is vied as a cause of organizational change. In the organizational imperative, the motives and actions of the designers of information technologies are a cause of organizational change. In the emergent perspective, organization change merges from an unpredictable interaction between information technology and its human and organizational users." (Markus 2003) It is not clear, however, how to identify which of these three causal relationships is that which is actually taking place in the organization.

Some research has investigated post-technological or post-organizational change to understand what the effective relationships were. Orlikowski and Barley, in looking at what IT and organizational research can learn from one another, provide a quick review of what has been studied from the IT side with regards to organizations such as the altering of communication patterns or organizational structure and whether it enhances the performance of individuals, groups, or firms (Orlikowski and Barley 2001). Their work advocates the importance of looking at both topics when studying one or the other in order to understand or appreciate the phenomenon under investigation. Orlikowski and Markus and Robey's review of relevant IT research includes studies of how IT promotes deskilling or reskilling, favors decentralization or centralization, alters communication patterns or organizational structures, and so on (OB 2001; Markus and Robey 1988).

If, from a technological perspective, we rely on IT to automate or enable processes and therefore the organizational structure, do we then rely on IT to also change or evolve when we want to make organizational changes? It seems that the opposite case is more likely. Technology changes at a much faster rate than organizations, such that maybe it is more difficult to instigate organizational change. Hitt and Brynjolfsson advocate that firms that are extensive users of IT tend to adopt a complementary set of organizational practices including things such as decentralization of decision authority (HB 2001). If true, there are serious consequences to be considered when choosing what technology to implement and what processes to enable.

The second implication of technology having a faster clockspeed than an organization is that when a technology change is put in place, it presents a unique opportunity to enforce change in the organization (Orlikowski 2001; Tyre and Orlikowski 1994). Hitt and Brynjolfsson, posit that one possible reason why many of the new organizational structures, such as the concept of a flat, learning organization, have not diffused rapidly despite large economic benefits is that they must be coordinated with changes in IT (HB 2001). However, it has been documented that new organizational approaches are required in order to meet the changing global environment (Galbraith 2000).

2.4.3 Challenges in Managerial Decisions

IT management has had much attention in research, as highlighted by Boynton. Studies have included the "managerial efforts associated with planning, organizing, and directing the introduction and use of IT within an organization" and these studies have received much scrutiny by scholars, practicing managers, and consultants (Boynton 1994). Ballou stated that "Top management support of MIS (Management Information Systems) means more than just allocation of funds…it also means assistance in establishing the chain of support needed in the various parts of the enterprise." (1978)

Since then, the importance of managerial commitment to substantial implementation projects has continued to be strongly promoted in leading business publications such as the McKinsey Quarterly and Harvard Business Review. A 2002 McKinsey report identifies the need for executive management to be more involved in technological decision making and be held more accountable for the outcome of IT efforts. Goodhue, in identifying the substantial amount of time and effort required up front for large data management efforts, highlights the importance of managerial commitment at all levels (Goodhue 1988).

There is evidence to show that organizations can be at an advantage if they have skilled personnel involved in both leading the change, and in the development and deployment of IT solutions. Jan Klein of MIT has recently published on the concept of "outside insiders" referring to the need for change agents within the organization to be involved in order to sustain true organizational change. Neo found that companies with previous experience of implementing IT are more successful in subsequent implementations than those that do not have experience (Bharadwaj 1999). Clark et al. characterize an organization's ability to rapidly develop and deploy critical IT systems as its *change-readiness* capability and attribute it primarily to the availability of a skilled internal IS workforce (Bharadwaj 1999).

There is a tension between long- and short-term IT project strategies that is often decided based on the financial means made available. Lack of sufficient financial support, often a function of ill-advised or-out-of touch management, is said to be most common reason for IT initiative failure and delay (Blouin 2004). There is a note-worthy distinction between long-term strategies and planning and short-term efforts, based on the desire to provide rapid payback to the shareholders. Again, Goodhue observed in his research that although most of the successful efforts were toward the short-term end of the spectrum, firms that had put in place stronger data architectural foundations appeared less likely to face problems integrating and sharing data across the organization. The strategy taken and resulting budget constraints have substantial implications on the capabilities the organization is able to achieve.

2.4.4 Summary of Challenges

The outcome of these challenges are failed implementations (Boynton et al. 1994) or shortsighted implementations that either only manage a portion of the data that is available (Goodhue 1988; Datamation 2005; Zahay 2003) and therefore only a portion of the lifecycle, or only vertically integrate a portion of the customers, partners, and suppliers. Few organization are able to manage effectively both the technological and social aspects of knowledge management for competitive advantage (Marshall et al. 1996). The challenges posed continue to prove difficult as the struggle to be successful in our efforts persists.

2.5 *Linking the Literature and Research*

This thesis primarily addresses the information-centric perspective of product development and the implications of successfully using product data management technology. This includes not only looking at data management in product development, but seeing how that reaches beyond engineering and into the enterprise, as well as what organizational implications are present.

The work done by Shaw et al. builds the case that enterprise-wide IT systems in the aerospace industry enable lean practices by providing an infrastructure to the enterprise. PDM technology takes advantage of the lean processes and practices that are already in place and serves as an enabler to additional improvements. The experiences laid out in the rest of the thesis serve to help the aerospace industry understand the challenges it faces in obtaining seamless information flow across the enterprise, and find ways to enable successful PDM implementations and integration throughout the enterprise.

Chapter 3. Meta Approach of the Research Design

3.1 *Defining the Research Area*

When starting the research process, it was unclear what aspect within the broad field of product development would be beneficial and interesting to study. After talking in general terms to industry practitioners in different aerospace companies regarding product development, it quickly surfaced that there are many questions and difficulties concerning information technology tools. When further questioned, it surfaced that there also is a trend of PDM implementations taking place. All of the companies interviewed were in the process of making PDM implementation decisions and are having difficulty from several perspectives. A major point of discord is the chicken-and-egg question of IT and organizations: Which one should drive - the process or the tool?

3.2 *Literature Revisited*

Although there is ample literature regarding data management and IT management, little of it addresses the questions being asked by industry. From a PDM software perspective, the literature is somewhat limited to vendors and consultants whose biases affect their reports. The literature also does not address the aerospace industry as a community and show what the difficulties are, or how prime and supplier companies compare in their respective needs and efforts. There is a communication gap between what IT suppliers are marketing and delivering and what is being understood and prepared for in the aerospace industry.

From the general perspective of IT management, literature does not have a snapshot particular to the industry and its needs when it comes to what the key challenges are and how to prepare the organization for the necessary changes and transition. There is a wealth of experience and wisdom in the industry from what has been done in the past, due in part to the abundance of mistakes made and the time already spent learning. This information needs to be harnessed and assessed to enable the industry to prepare for the challenges ahead.

Finally, from an LAI perspective, emphasizing the importance of lifecycle applications and enabling enterprise transformations is a fundamental lens for viewing PDM implementations in the industry, and then extrapolating these to other business solutions. The research has underscored the criticality of data management across the lifecycle. Once this criticality is understood, organizational leadership can then prepare to address some of the common challenges and disconnects that occur, while framing the lessons learned in the proper context.

3.3 *Justification for the Methodology*

The first step of the research was to identify the proper research questions and approach. To do this, five consortium members who had been involved with their companies' PDM efforts were invited to attend a one-day workshop at MIT. The purpose was to uncover and understand the key questions companies faced, and then determine the proper research strategy to gather appropriate data. Before attending the workshop, attendees were asked to provide their top three challenges with PDM.

Halfway through the workshop, a focused, comprehensive list of foremost questions framed the research agenda. Given the broad nature of the questions and the state of the literature, the research methodology chosen was an exploratory and descriptive approach. It was decided that a structured interview process was most appropriate. A survey would not allow for the exploratory needs and would collect a much more limited set of data. Alternatively, unstructured interviews would be inefficient given the success of the workshop in defining the research space.

During the workshop, the desired status of personnel for interviews was discussed. Only people within companies working on PDM specifically would be interviewed. It was decided that a separate set of questions for someone at the site or company level and program level was appropriate. Over time, the importance of this became apparent. Within different types of aerospace companies, for instance between prime and sub-contractors, there are large differences in the size of 'programs' and in how much input a program has on PDM selection and implementation. This affects the success of the implementation as well as by whom the costs are borne. Also, levels of PDM maturity span a wide range in the industry. Thus, getting a representative cross-section of the industry, and across programs within any particular company, was desirable in order to get an understanding of the state of PDM maturity across the industry.

By the end of the workshop a sizeable amount of work had been accomplished, meeting all of the research objectives, and an exchange of experience and wisdom between attendees had occurred. A preliminary draft of specific questions for the interviews was developed, which would be reviewed, piloted, and fine-tuned over the next four months. The key research questions and methodology were decided, and some potential metrics were discussed for measuring capabilities of the systems.

The expected outcomes of the research were primarily answers to the key research questions that were identified. Beyond that, it was understood that some good practices and common challenges would be identified, as well as a more comprehensive and context-specific understanding of what is occurring within the industry. This information is useful in two ways: 1) it can help companies make more educated decisions with their investments; and 2) it can identify gaps between prime contractors and their suppliers, which has large implications on data management across the lifecycle. Ultimately, there were unexpected findings that provided additional value to the research.

3.4 *Overview of Data Collection Execution*

In all, nine different sites representing six different companies were visited. The first phase of the research included the structured interviews, which covered a broad number of topics related to their PDM system capabilities and implementation approaches. From a preliminary analysis of the data, several interesting findings emerged that were not expected from the original key research questions. A first glance at the data highlighted similar trends regarding the goals and challenges faced by each company. Each implementation is a unique story, however, shaped by differing characteristics: the age and type of a product; the vendor tool selected and the challenges of fitting it to the organization; how the management and implementation team went about communicating between upper management and the user community; and how long the company has been working on a PDM solution.

From the initial phase of the research, some questions surfaced that had not been sufficiently considered or addressed by the interviews. With the planned intent of using follow-up case studies to generate a more in-depth understanding of emergent research findings and gaps, two new questions were posed. Two companies were chosen for the case studies based on their divergent experience, organizational characteristics, and product specialty. By design, the two companies highlighted very different decision and development progressions, as well as levels of success.

Chapter 4 . Detailed Approach

4.1 *Setting the Research Agenda*

4.1.1 Exploratory Interviews with Industry Practitioners

Once it was decided that the research would be conducted under the auspices of the Product Lifecycle Knowledge Area at LAI, it took some time to determine what area of research would be fruitful and interesting. Several telephone interviews were conducted with industry representatives known at LAI. The discussions revolved around what these representatives were doing within their product development departments, what they were struggling with, and what answers they would like. Topics discussed include problems with specific engineering IT tools such as non-standard interfaces and non-intuitive software changes. These are largely due to vendor merges and upgrades. Another topic discussed looking at instant messaging and how it is changing collaboration and communication across the extended enterprise.

The topic of product data management, its importance to the business, and how it related back to the standard process and tool discussion also resurfaced frequently. After pressing the discussion on PDM more, there was some uncertainty revealed in terms of decisions made and how they compared to others across the industry relative to how the problem was being tackled. There was also indication that this IT tool had additional impact within product development. That the tool is expanding its reach across processes, and that the ability to manage product data across the lifecycle is becoming ever more important made it an attractive area of study. Its subsequent investigation would go beyond the technology itself and touch upon a wide array of issues, including cultural barriers in organizations, IT architecting for the enterprise, and standardization of processes to automate them with a standardized tool.

4.1.2 Exploratory Field Trip

There was enthusiasm from the industry on the topic selected and many offered references and colleagues. An exploratory field trip was taken to a member company fully engaged in its PDM activities. As a prime contractor, it has several legacy programs and many legacy IT tools being examined anew. During the three days, several personnel involved with PDM activities and similar efforts that had taken place in the past were interviewed. They included PDM system architects, programmers, a design engineer, an engineering director, and process owners.

The goal of the trip was to understand the "big picture" of PDM as well as what was actually being faced within these organizations. The range of questions now seems naïve, but at the time, the technology, its perceived place in the organization, and the implications of implementing it, were not obvious without seeing it. Questions ranged from "What is a PDM and what does it do?" to "What are the difficulties in implementing the system?" and "Why is there an entire department of people working on this problem?" Understanding the metrics being captured was also an important aspect of the trip. They would be useful in evaluating companies' performance, and in comparing the efforts across companies that had been undertaken.

4.1.3 LAI-Hosted Workshop to Define Research

Based on what was learned from the field trip, there was a need to survey the industry more broadly and achieve a representative sampling of what issues were being faced, not just in prime companies, but in the supply chain and other members of the community as well. To identify the proper research questions and approach, several LAI consortium members who had been involved with their companies' PDM efforts were invited to attend a one-day workshop at MIT. The purposes of the workshop were to:

- Define the proper scope for the research, including pressing, high-impact questions
- Develop a plan for collecting data
- Gain the continued participation by those attending in the research design and execution

Five industry members representing four different company sites were able to attend the workshop. In the first few hours of the workshop, more than 27 different topics related to PDM were raised; of these, three were highlighted as overarching themes that encompassed many of the others. They were:

- What are success factors in implementing PDM at various levels of maturity – best practices?
- How do we address requirements for PDM systems while balancing program and corporate needs?
- How does PDM support large-scale integration of traditional functions?

From there, each attendee was given the opportunity to describe his or her ideal report of findings at the end of the research. Those desires that could be addressed given the research timeline and available resources were highlighted as potential areas to explore. Some of the resulting questions were:

- What percentage of companies are managing data with PDM? What kind of data are they managing?
- What are the pre-requisites, if any, for implementing PDM?
- What functional organizations are using PDM, including customers, suppliers, etc.?
- How are people deciding what data is and is not managed by PDM?

Given the questions that were raised and the literature available on the industry and on PDM in general, the methodology chosen was an exploratory and descriptive approach. It was decided that a two-phase approach should be taken. Phase One would consist of a structured interview process to gather initial data on the majority of questions posed. Case studies would comprise Phase Two, providing an opportunity to further explore specific questions identified in Phase One that had not been fully understood or flushed out.

In the afternoon, brainstorming on what particular questions should be asked was done. More than 100 questions were thought of that fell into four major categories: company and product context; IT architecture; implementation approaches and plans; and extent of use. The remainder of the workshop was used to determine the scope of the research, including defining deliverables and a timeline.

Feedback from the attendees indicated that they had gained some knowledge from one another during the conversations. They also felt that the research was off to a good start and a worthy topic chosen given the time and resources that it would require to carry out.

4.2 *Data Collection Design (Interview and Survey Design)*

4.2.1 Selecting Research Participants

Within the industry, the full spectrum of 'not thinking much about it' to 'been doing it for 10 years and we are almost there' exists regarding the maturity of PDM systems. Companies were initially contacted through LAI consortium contacts and personal contacts made at the LAI annual plenary conference. Only companies who were actively implementing, or had implemented PDM already, were considered for the site visits, in order to benefit from their experience and understand their decision-making process. It is known from phone interviews that there is a portion of the industry not yet using PDM. However, time constraints did not allow for a more comprehensive survey of the industry overall to know exactly what percentage.

At any given company, there are large differences in the sizes of 'programs' and in how much input a program has on PDM selection and implementation. This affects the implementation approach and who bears the costs. Also, because the levels of PDM maturity cover a wide range in the industry, getting a good cross-section of the industry, and across programs within any particular company, was desirable so as to have an understanding of the state of the industry.

Each company (including different sites or lines of business within a parent company) contacted that was at least in the process of implementing a PDM, and therefore actively engaged in PDM activities, was included as part of the research. Prime contractors, suppliers, and federally funded research and development centers (FFRDC) were all included. Between one and four programs were considered at each site, depending on the extent of their implementation and the breadth of these programs. Three programs was the desired goal in all cases, but some of the smaller companies had more limited implementations than others at the time of the research.

Overall, nine sites, 27 programs, and 48 people were involved in Phase One of the data collection process. The different product variants range across spacecraft, aircraft, and weapon systems.

4.2.2 Interview Document Development

During the workshop, a first round of potential questions was created. Over the following four months the list of questions was reconsidered, revised, and re-focused, based on the key research questions and a desire to gain the most information within the least amount of time required for an interview. A review and comment procedure was used with the five workshop members to help in this process.

Once an alpha version of the questions was ready, the interview process was piloted at a single site where only one program was evaluated. Feedback from that opportunity was implemented and the plan to begin collecting data was put into place. The first site visit unintentionally served as a second pilot for the interview process. At this site, three programs were interviewed, along with a site history and site perspective representative. In other words, a full data set was taken. Changes were incorporated from that run as well, but the interview documents and process did not change significantly after that point. This second site was revisited later in the year to gather additional information reflecting any of the implemented changes from the first trip.

4.3 *Data Collection Process: Phase One*

For each collection site, a two- to four-day period was allowed with the intention of having time between interviews to take extra notes and provide opportunity to collect any data not ready at the time of an interview. For each site, an introductory interview was performed with the intention of understanding the history and current culture of the company. This interview took an hour or less and was typically addressed by the main contact, a communications (or public relations) person for the company, or a combination. Structured interviews were then administered at both a site and program level, covering a broad range of topics related to their PDM system capabilities, implementation approaches, and experiences. The structured interviews had several components and typically required two hours to complete. Site interviewees were predominantly directors and senior managers in either the engineering or IT organization. For the programs, the interviewees were predominantly program managers or chief engineers.

4.3.1 Interview Documents and Tools

For any given site visit, there were four types of interviews that took place in the following order: company history and context interview; site interview; program interview(s); and process interview. The purpose of the order was to gain a broad understanding initially of the company, which would help me put into context the answers received during the site interviews. Because of the difference in how much involvement programs have across companies, there were some questions that were appropriate at a site level and not a program one and *vice versa*. Having the site interviews prior to the program interviews eliminated talking to programs about things into which they had no visibility. If the programs did have information regarding certain questions, chances were good there was also a site perspective. Knowing both at that point would help identify any inconsistencies in what the site and programs perceived as happening.

Each site and program interviewee was required to sign a consent form at the start of the interviews to meet the MIT Committee On the Use of Humans as Experimental Subjects requirements. For these interviews, a preliminary questionnaire was sent out asking characteristic and contextual questions about the site or program, which could be answered easily without being formally administered. The purpose of this was to save time collecting information during the actual interview, and provide background data about the site or program prior to the interview.

Each site and program interviewee also answered a PDM maturity survey. Modeled after the Lean Enterprise Self-Assessment Tool developed at LAI, the survey required interviewees to rank the maturity of their particular PDM use and capability in four areas. The areas were:

1. Integration of product data across the product lifecycle

2. Extent of supplier/partner integration
3. Management of workflow electronically throughout the product lifecycle
4. Integration/compatibility with current systems/applications

1. Integration of product data across the product lifecycle

Scale:

1	2	3	4	5
Product data (PD) in several disparate locations; difficult to locate and retrieve data	PD residing in several legacy systems; major systems are interfaced with PDM	PD residing in primary legacy systems; legacy are integrated with PDM; PD interfacing with prime suppliers and tier 1 and 2 suppliers	Only one or two legacy systems per major function; integration with PDM; All prime and tier 1, 2 supplier PD is integrated	All PD stored in a single database (DB) including critical supplier data including international partners or supply chain

Figure 4: An example of one of the four data management maturity questions and its scale.

Although there is some overlap in the questions, the goal was to obtain a comprehensive measure of to what extent an organization was using PDM's potential capability. Five different levels were defined. Interviewees were asked to indicate both the current and desired states of the organization, and were allowed to supplement their answers with comments such as why they fell into to one versus another, or were almost at a certain maturity.

Many of the same questions were asked of both the site and program interviewees in order to understand the two perspectives. The site interview had more emphasis on corporate vision and methodology for implementing across the site, whereas the program interview included more specific questions regarding how data is being stored, what decisions they had power over, how they feel the implementation was handled, etc.

As part of the structured interview, there were three different tables used to collect information. The first is a matrix of what tools are being used to manage what types of data. Both current and past or future practices were captured, depending on whether or not the organization had completed its implementation. This information was very useful in assessing the actual use of PDM software versus other software in data management, as well as how companies were transitioning with the new implementations.

The second table tried to capture what the other major business systems were for the company and how they were being integrated with the PDM tool. The third table was an attempt to capture how many and what types of users were actually using the PDM. This included identification of external users such as customers and suppliers. The tables can be viewed in Appendix B.

4.4 *Data Collection Process: Phase Two*

As decided during the research workshop, a case study approach was used following Phase One to address some questions or aspects of PDM that could not be understood or were overlooked during Phase One. Based on the findings from the initial interview data, two new questions were posed for exploration in case studies:

1. What was the initial tool selection process?
2. How are the technology and organization evolving over time?

The first question was posed to understand both what initiated investment in PDM technology and what process and factors were used to select the particular tool that was bought. Figure 5 illustrates a generic, expected process. The two companies' actual processes are illustrated in the case study chapter.

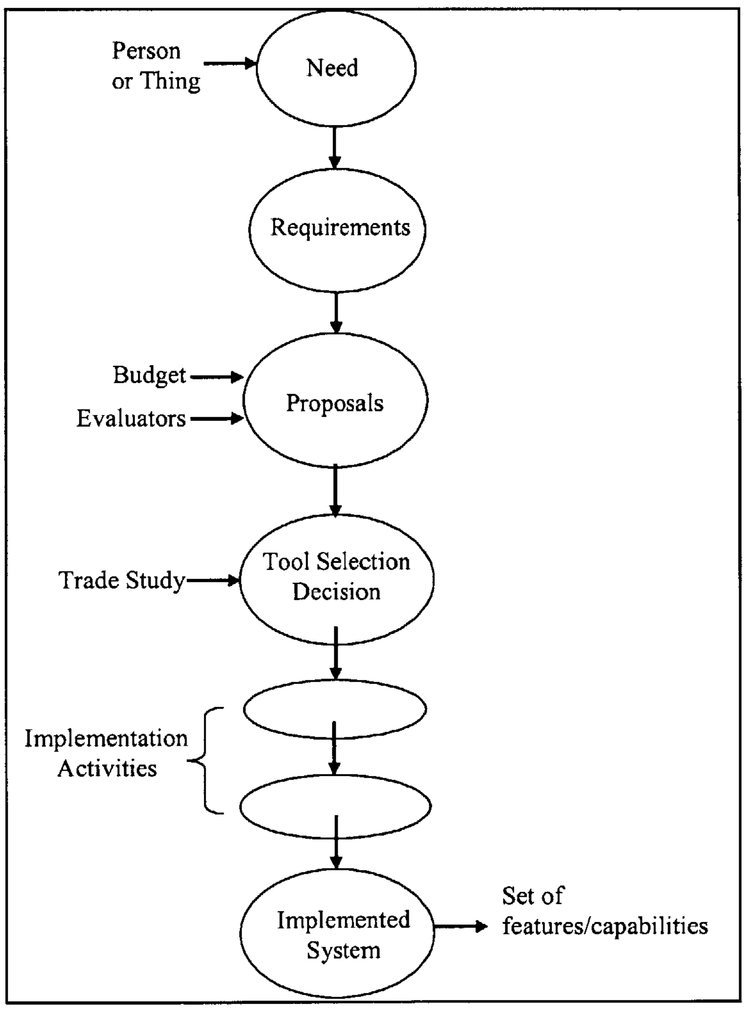

Figure 5: A representative process of how a company would procure a commercial PDM.

The motivation for the second question was due to the evolution of the tool and the potential impact on the organization's processes that would affect the way engineering is performed. It was desirable to know how much the tool was driving change in the organization versus how much influence the organization and processes have on the development of the technology.

Two companies were chosen for the case studies based on their experience, type, and availability. By design, the two companies highlighted very different decision and development progressions, as well as levels of maturity.

Chapter 5. Phase One Analysis: Survey and Interview Data

5.1 *Introduction*

Survey data was collected from two perspectives at each company site: the overarching site perspective and at an individual program perspective. Data was collected only from companies that were engaged in PDM activities. In most cases, three programs were selected for interviews. The goal of selection was to get a representative sample of different lifecycle phases, ages, and program types at any given company site.

The questions asked and the results presented here cover quite a range including: the types of data being managed, the tools being used to manage data, the amount of cross-functionality and inter-company connectivity, implementation approaches, how much money was spent, and what the perceived value of PDM is. At every site, a separate interview inquired whether stakeholders and their needs were addressed in the requirements development of the IT solution.

When comparing results between supplier and prime capabilities, it is important to note that companies were selected based on whether or not they were actively engaged in PDM activities. For the supply chain, those interviewed may be less representative of their population than the prime sites interviewed are for theirs due to the different levels of activity occurring in the two populations.

5.2 *Participating Site Characteristics*

All of the sites interviewed were within a one-year timeframe of a major PDM change. A few were very young in their solution roll-out to programs even though the development of their solution had been taking place. Other sites had finished the bulk of the roll-out and were planning their next step. All of the sites were all actively engaged in PDM activities.

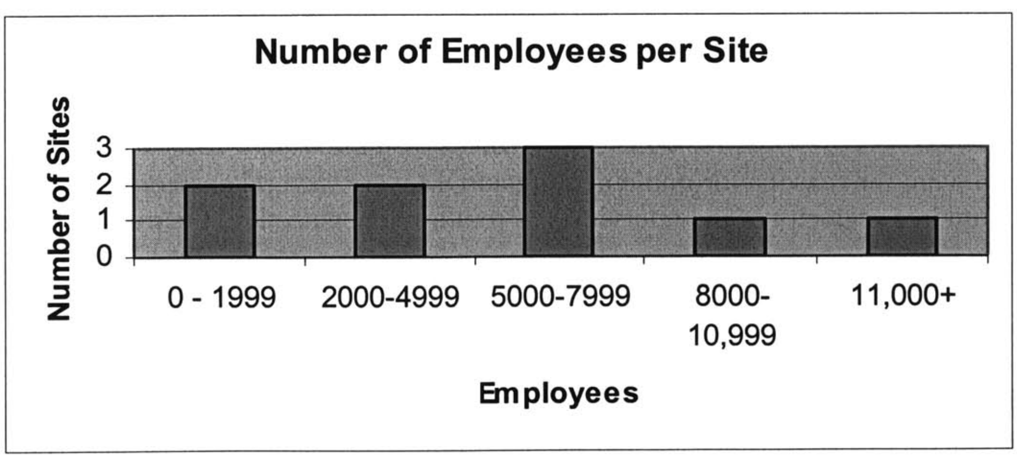

Figure 6: Employee profiles for eight of the nine sites studied.

Figure 6, above, indicates the relative size of the participating sites based on the number of employees.

All of the sites had chosen and were implementing their PDM with the expectation that it would be the standard data management tool for all of the programs at the site. The only exceptions to this were classified programs that were required to remain on individual systems and sunsetting legacy programs where the immediate cost or priority could not be justified. All but one of the sites was part of a multi-site or company-wide effort. The one site involved in an independent implementation has recently been given new corporate mandates, shifting its individual efforts to date.

The sites can all be characterized as matrix engineering organizations and are subject to meeting ITAR requirements. All but one of the sites claimed to regularly practice some combination of Lean and Six Sigma practices.

A majority of the sites are working under a corporate vision of standard processes and tools, and enterprise-wide system capability. However, based on the interviews, what is being decided and flowed down from a corporate perspective is often not what is being implemented due to several reasons as discussed in section 1.5.

5.3 *PDM Technology Characteristics*

Within the nine sites, four different vendor PDM products have been implemented (regarding new implementations, not legacy technology). One particular product is being used at a majority of the sites. Regarding the licensing strategy, four out of eight site responses indicated that licenses for the PDM software are allocated from a pool while two others indicated that the licenses are named. The remaining two use a combination of both strategies, partially for legacy reasons. The total number of licenses ranges widely for the nine sites; the smallest is 15 at a supplier site where they have recently completed their first full PDM implementation on a single program, and the largest being within a prime site where there are close to 3000 active licenses.

5.4 *Justification for PDM*

5.4.1 Reasons For Implementing a PDM

When asked what the reasons for implementing a PDM were, several answers were given but some came up in a majority of the interviews. From a site perspective, the most frequent reasons given were:

- A need to replace legacy tool(s) (4)
- To reduce cost, time to market (3)
- Centralization of data (2)
- Elimination of redundancy (2)
- Concurrent engineering (2)
- Reducing tool variability - focus on commonality and convergence (2)

Other reasons included capabilities afforded by PDM such as enhanced design capabilities, providing on-line access to data and improving data, supplier, and customer management capabilities.

When asked to identify the overarching reason for implementing PDM between a competitive-, internal-, customer-, or supplier-driven impetus, the overwhelming response was internal. Its frequency was seven to two over competitive.

5.4.2 Building the Business Case

As the case studies will illustrate, it seems very difficult to justify the investment for a PDM without a "burning platform"[1]. In many cases, this is either a need to replace a legacy tool that is no longer being supported, or the miracle solution to a failing business model. Very rarely does the data indicate that a PDM implementation was successfully marketed and chosen as a smart, strategic move that enabled the company to stay competitive and on the technological forefront.

All nine sites 'had' a business case, but few had actual numbers or metric typically found in business cases that they could meet. In cases where it was already realized that a PDM was necessary, the business case was still created as a formality of requesting a capital expense. For most, the business case's merits rested on unclear metrics such as cost avoidance, and minor savings due to reduction in legacy systems or reduction of people doing menial tasks such as searching for data.

No one interviewed from a site perspective claimed to have verified the numbers stated in the original business case. There are, however, ways in which cost savings can and have been realized that are dependent on how successful the implementation and adoption of the system is. For example, companies did experience cost savings specifically from a reduction in the staff required to manually transfer and enter data when the need for them was eliminated – something not all companies have been successful at doing. One company shared that they had an entire department of people tasked with finding data, while another, was paying three Master's-level engineers to manually reconcile as-built and as-design BOMs due to the paper system.

A second potential cost savings is the opportunity for companies to outsource IT needs that have been heavily dependent on internal IT competency. Internally developed solutions became highly customized and specific to particular needs, going back to what was discussed from a functional perspective. If a suitable system for the organization is available and selected, then many of the customizations that are being maintained internally between legacy systems are no longer necessary. This reduces system complexity and cost.

Although it is hard to find consistent metrics in the industry, there is an expected cycle time reduction for design or engineering change requests (ECR) due to the automation of the workflow. Some companies have shown dramatic reductions in their cycle times, but it has typically been observed beyond the original design activity and can be attributed to multiple

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[1] A burning platform typically refers to when a company, program, or project is in a dire business situation and something has to be done immediately about it. Typically requires that action to become priority at the cost of others; similar to the concept of "fire fighting."

initiatives or changes taking place simultaneously with the PDM-induced changes. This made it difficult to find cycle time reductions specific to PDM implementations.

Finally, there are the intangible unknowns that will likely never be measurable or fully understood. Savings due to a reduction in errors, lost or misplaced data, and rework due to having the wrong data at the wrong time are expected benefits associated with centralization and stricter configuration management of product data. There is also a benefit derived downstream due to the increased quality of the data.

5.5 *Spending Characteristics Regarding PDM*

Understanding how funding for PDM implementations is allocated differently between sites provides insight into priorities. It also provides data that might lead to understanding why some implementations are more or less successful.

5.5.1 Money Spent on PDM Implementations and Support Activities

Site-level interviewees were asked to indicate, within a given range, the total amount spent, the timeframe that amount was spent over, and what it was spent on. There were typically costs that were borne by the program or project budgets, especially within prime sites, but overall the majority of costs were carried as an overhead or special expense at a site level.

Figure 7 illustrates the bins used to capture overall spending. Data was collected for all nine sites. There was some difficulty in obtaining accurate cost data, as well as the timeframe over which it was spent because many sites have ongoing efforts regarding their PDM infrastructure. Therefore, each interviewee was guided in defining the most recent or relevant "major" PDM implementation for the site. The total cost and timeframe were then focused on that effort.

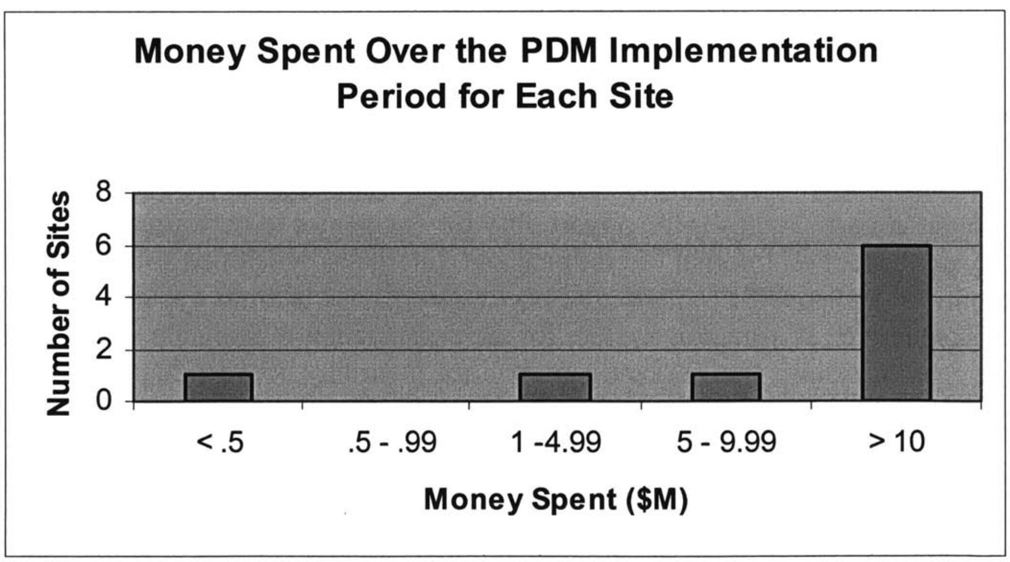

Figure 7: Total spending on the most recent, significant PDM implementation at the site level.

The graph shows that a majority of the sites interviewed are spending greater than $10 million on their implementations. Figure 8 illustrates, from the same cost data, approximately how much was spent on a per-year basis. Many of the interviewees identified a longer time-frame so their money spent on a per-year basis is not as radical as it first appears. In order to calculate the per-year amount spent, the value bin indicated by each site was halved (using $15M for the >$10M bin) and divided by the number of years it was spent over as indicated by the interviewee.

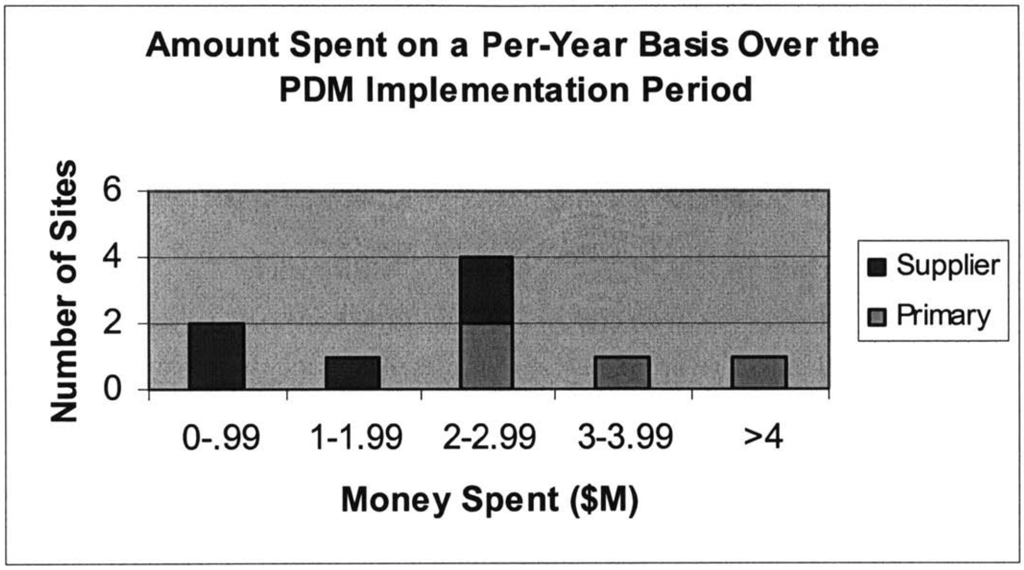

Figure 8: Money spent on a per-year basis for the most recent, significant PDM implementation at the site level.

The data in Figure 8 appears to be much more normal, indicating that the bins chosen for the actual money spent were reasonable considering the industry being researched and their current PDM efforts. It also verifies a suspected trend that suppliers are spending less than prime companies. According to an Aviation Week and Space Technology article in 2003, the Aerospace and Defense industry's average IT budget was 4% of total company revenues (AWST 2003).

5.5.2 Comparison of Spending

Each interviewee was shown a pie chart with five categories and asked to indicate what percentage of the total money spent over a given timeframe was spent in each area. The five categories are: required hardware and software costs for the PDM system; process development; consulting; data quality and migration; and training and other.

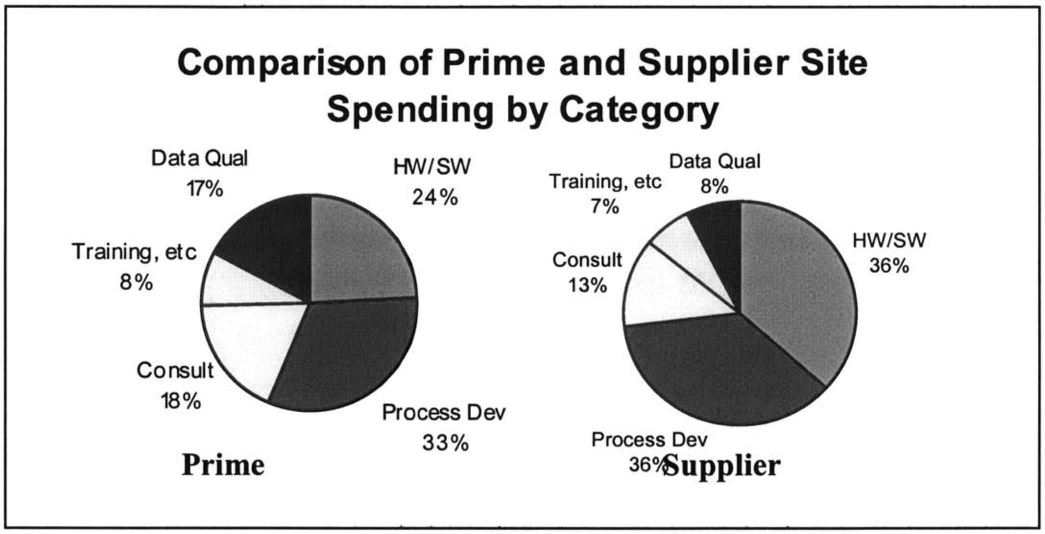

Figure 9: Comparison of how prime and supplier sites spent money based on five categories.

In Figure 9, the average spending between the prime and supplier sites is compared. Suppliers overall have spent considerably more money on required hardware and software for PDM, and much less on their data quality activities. Data quality was defined to include any clean up and migration costs as transitions take place from legacy systems to new.

Typically a prime site will have more legacy data and infrastructure to address which might explain their higher Data Quality expenditure. That supplier sites have spent more money on the hardware and software may be an indicator of two factors: they could have had less infrastructure in place to begin with (such as computers and servers) and it could be caused by an economies of scale factor. Typically, suppliers are buying fewer licenses and doing less external integration, so their cost per person or station will be higher.

5.5.3 Statistical Analysis on Spending

A very limited amount of the data collected was appropriate for doing any statistical analysis. Those that were appropriate were analyzed using non-parametric methods in order to show statistical significance rather than try and draw conclusions based on what a chart looked like – a dangerous practice commonly employed. This section and section 5.9.2a) statistically support the conclusions drawn on the money spent on PDM and the ways in which data is managed respectively.

In order to understand whether there was a real difference in how the companies were spending money, statistical tests were used to analyze the data. The hypotheses tested were:

1. Is there a difference between prime and supplier companies based on how much they spend across categories?
2. Is the money spent independent of the category?

A 2x5 ANOVA was planned with one factor being the two company types and the second being the five categories. Unfortunately, the company data did not pass the test for normality (KS; p =

.036 for supplier type) or homogeneity (Levene; p = .004) required to run the ANOVA. The data across categories of spending however met both assumptions.

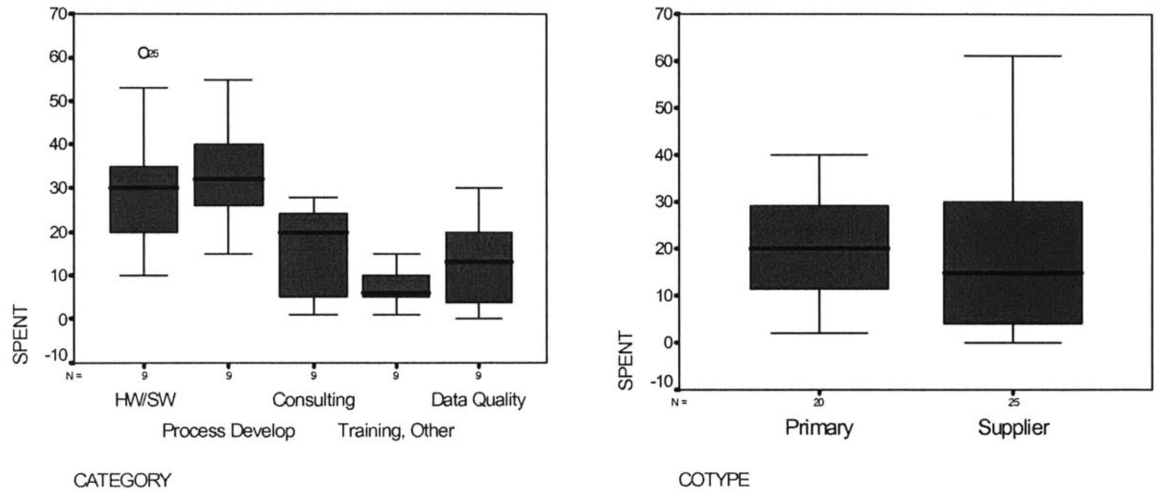

Figure 10: Graphical representations of the data categorized by company type and spending category.

The company type data did not meet normality requirements while the spending category data did for an ANOVA. A one-way ANOVA was used to check the second hypothesis. Since the data across company type did not meet the assumptions, a Kruskal-Wallis non-parametric test was used to test the effect of company type.

From the ANOVA, a very strong significance ($p < .0001$) was shown across the categories, meaning that money was not being spent equally across all five. This warranted comparisons across the five categories. The Tukey method was used as a *post hoc* test to do pair-wise comparisons. From the Tukey, there was significance found between the pairs of categories as shown in Table 3.

Table 3: Results from the Tukey test showing those spending categories that had a significant difference using alpha = .05.

			95% Confidence Interval	
(I) CATEGORY	(J) CATEGORY	Significance	Lower Bound	Upper Bound
% HW/SW	% Consulting	0.056	-0.28	31.83
	% Training and Other	0.001	7.72	39.83
	% Data Quality	0.012	3.17	35.28
% Process Development	% Consulting	0.013	2.95	35.05
	% Training and Other	0.000	10.95	43.05
	% Data Quality	0.002	6.39	38.50

As expected, based on the box plots for the categories, there is a pattern of the same two categories being significantly different from the HW/SW (hardware and software costs) category and the Process Development category. Money being spent in both the Training and Data Quality groups is significantly different from the HW/SW and Process Development groups. The resources allocated to Consulting have a marginally significant difference from HW/SW.

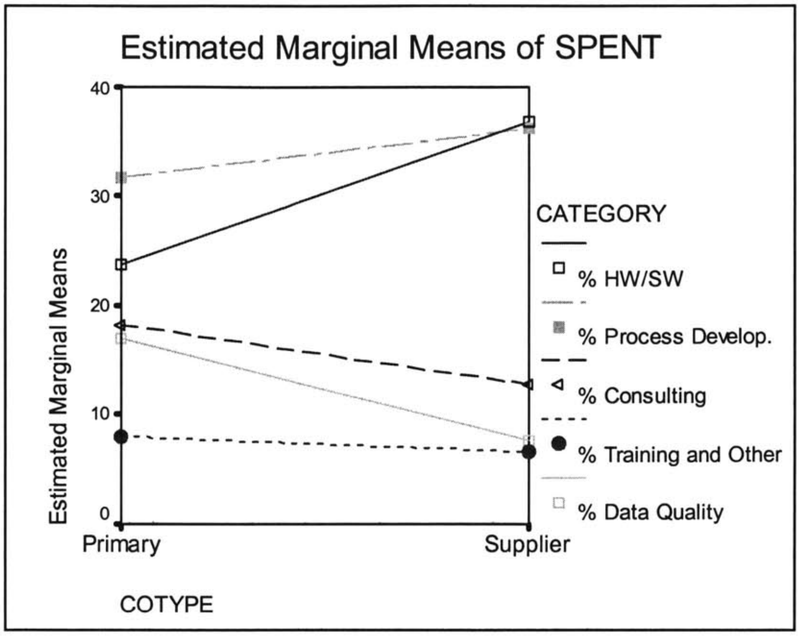

Figure 11: A graphical representation of the marginal means for the spending categories across company types.

Figure 11 above shows how the proportional amount of money spent in each category compares across the prime and supplier companies. This figure helps the reader visualize how the spending varied between the two company types for a given category.

A Kruskal-Wallis test was used, because of the normality and homogeneity violations of the company-grouped data, to test whether there was a significant difference in how the two groups spent money. The result showed no significance ($p = .50$), meaning that the money spent within each category by prime companies was not statistically different than that spent within each category by supplier companies.

5.6 *Designing the Solution*

5.6.1 High Level Requirements for PDM

Every site and program was asked what their high level requirements for their PDM implementations were. These were defined as the 'must haves' for them to consider implementing a particular solution. The responses were not guided any more than thus, and interviewees took different approaches in how they answered the question.

From a site perspective, the following answers were the most frequently given that satisfied the question:

- Compliance with company policies and regulations (ITAR, BR, etc) (3)
- Ability to migrate legacy data (digital and non) - scalability (2)
- Increase speed in the release process, access to data, etc (2)
- Facilitate collaboration, concurrent design activity (2)

- o Integrate with other systems both upstream and downstream (ERP in particular) (2)
- o Minimize impact to programs/do no harm (2)

There were some responses given that did not necessarily meet the criterion for a high-level requirement, but did highlight what might be the most desired or expected functionality associated with what PDMs are typically expected to provide. For some, these responses represented capability that did not currently reside in the company's data management infrastructure:

- o Basic doc and configuration mgmt (3)
- o Central repository for design data (2)
- o Automated workflow (2)

Other insightful comments included the need to at least replicate the functionality that currently existed in legacy systems including legacy PDMs. This can sometimes be a challenge given the old systems and the level of integration that already exists between them. The industry group that helped develop questions was originally interested in whether collaborative design in a virtual environment would be a requirement for most sites or not, given the advances in digital technology. In most cases, the response to this was "No, but it would be nice to have."

5.6.2 PDM Implementation Leadership

The choice of who led the implementation included gathering requirements and planning training seems to have an effect on the success of the implementation overall. This is especially prevalent in the case study data. From the interview data, there is a trend in the companies that have more PDM implementation experience, to ensure that the team in charge of implementing the PDM is at least half engineering, if not more, compared to the IT personnel.

The selection of teams changed slightly over three phases: the solution development, implementation, and post-implementation support. Companies with more past experience included a broader scope of stakeholders in the solution development phase than those with less experience. All of them included some combination of engineering, IT, and vendor personnel with one exception that did not have a vendor directly involved initially. Over half of the respondents used their internal IT personnel and a vendor or consultant contingency for the implementation of the tool, but most used a smaller set of personnel. For the post-implementation phase, all respondents used a team that was either completely or primarily composed of IT personnel.

Anecdotal evidence is provided in the case studies regarding the choices made for the implementation teams and what had been learned from past experience.

5.6.3 Implementation Approach and Considerations

All sites, overwhelmingly, were involved in phased implementations. They were phased, however, in different ways. Depending on the homogeneity of the site in terms of products, the current systems in place, and the amount of legacy data to be addressed, each company took a slightly different approach in how they migrated data and brought the new capability to the site overall.

Most sites phased their implementation in one of two ways: either based on functionality such as design, and then analysis, etc., or by program. Grossly speaking, sites with very distinct, large programs that have a large amount of legacy data tended to phase the PDM capability program by program. For those with more homogeneous products, the trend was to phase by function, bringing all users within a given function on to the system simultaneously. Other considerations that affected how sites chose to deploy the PDM capability were program schedules, the phase a program was in, and the amount of budget or personnel support available at a given time.

5.6.4 Software Modifications

For PDM-type applications, software customizations have come to be expected in order to prepare a COTS product to meet the site's needs. The amount of customization and upkeep, however, is expected to be less than that required to keep existing legacy systems operating and integrated. Actual customizations varied greatly, based on the interviews, but typically fell into three main categories: integrations or interfaces with other IT systems, necessary changes to the vendor SW to meet industry processes, and special capabilities that are not out-of-the-box but are standard within the organization such as reporting.

Some sites chose to keep certain legacy systems up and running, and were therefore constrained to customizing the interfaces each time a software upgrade took place. Four out of eight respondents indicated that they had some customizations made to either the data model or heavily altered the workflow to more closely meet standard processes. For other sites that chose to do a lot of customization to the COTS PDM product, it was generally focused on the user interface in order to make it easy to use, and in some cases, resemble the interface that users were familiar with. One site created its own user interface, not utilizing any of the OTB interface provided.

There was an indication from the program interviews that they would have preferred more customization to the tool provided to them by the site. Due to the costs of the customizations, however, they were generally not granted.

5.7 *Preparing the People*

5.7.1 User Training

The sites and programs were asked how they administered training, how successful they thought it was, and why. The approaches varied greatly across the sites and even within a given sight over the duration of the complete implementation.

The research found many shortcomings in how much focus was spent on training or how it was approached. From the interviews, even well-planned and -attended training sessions did not guarantee a knowledgeable user community once the new system is in place. Although six out of eight interviewees answered affirmatively when asked whether they would consider their training to be successful, the yes was always accompanied by 'sort of' or 'no'. One interviewee answered described his site's training as "functional".

a) The Right Training

When deciding who should be trained, some site's initially made poor use of user's time by giving everyone the same generic training. Others created specific training for specific user groups and provided on-line materials as well as user manuals. One of the difficulties with training is getting the user's to retain what they learn and be able to apply it when they actually need to use the system. One way this was addressed was by training users that would serve as the local subject matter expert for that particular user group such as an IPT or functional organization. This helped take some of the pressure off of the help-desk regarding minor usability issues and lessened the frustration of users.

The most recent training efforts were usually classroom based and might include a couple-hour introductory for all of the users followed by specific training geared toward individual user groups.

b) Timing of Training

Some sites, early in their PDM journey, would wait and train users once the system was up and running. The difficulty with this was that users typically would not fully grasp how to use the system the first time they were trained on it. This caused the need for user support to continue training past the deployment, taking away its ability to address systemic issues rather than user questions.

Based on experience, all of the sites interviewed now plan training as close to the go-live date as possible and plan on subsequent training post-deployment. Depending on the number of users that need to be trained, the furthest before the go-live that any site trained was eight weeks

c) Reducing Push-back

Something that was often underestimated was the need and difficulty in communicating the impact, or change, that the new PDM was going to have on the users' everyday activities. Some sites used brown bag luncheons and user group meetings as optional times to reach out to the user community. Another created tip sheets for certain, common activities that users commonly had problems with.

Overall, consensus was that more effort needs to be spent in communicating to the user community the significance of what they are about to experience. As described by a director of design engineering, "Where [training] has been a success, it was because the people understood the impact. This isn't just a PDM - it's their new job. In other instances, some heard but didn't listen." Others commented as well, saying that making the transition more 'real' to the user community would have lessened the resistance.

d) Development of Training Materials

Each of the sites had a slightly different make-up for their group in charge of developing the training materials and teaching the classes. Some sites had the software vendors involved with the team or left them on their own; others had only the IT-portion of the implementation team do it; some were a mix of all three.

e) Major Take Aways

Training evolved in all cases as experience resulted in lessons learned. Some of the important changes that the sites made over time were:

- Formalizing the training and fully developing it;
- Better use of management as an enforcer; and
- Moving training as close to deployment as possible so that users could sooner put to practice what they were taught

5.7.2 Involving the User Community

Communication with the programs, where the bulk of cultural resistance sits, is often overlooked. The site representatives differed on how they thought this should be addressed. Some interviewees thought that they should have involved the programs in all phases of the implementation. The difficulty lies in "getting their attention." Once the programs understand what is happening, why, and have more or less agreed to it, the implementation can then move forward. If the programs, their managers, and representatives are confused or left out along the way, there will be questions and objections once the changes decided upon begin taking place.

A somewhat alternative view is to "Have program people do program work - not process improvement." This is important as well, that they should still be doing their job and not someone else's. However, another interviewee suggested that they would have the program people involved in defining the requirements at the process definition level and not beyond that. The emphasis here is assuring that the requirements developed address the actual needs from a program perspective. These different views emphasize that balancing the user community involvement is just that – a balance.

5.7.3 Management Support

The degree of management support for the nine sites varied greatly. Five of the sites claim to have had good management support which included regularly scheduled meetings, bottom-up concerns being heard and addressed, and consistent support for initiatives and events regarding the implementation. Those who were less satisfied with their management support often said that management was supportive in word, but not involved or invested in the PDM effort, implying a lack of action on management's part. Many saw competition for resources and support from other large business system initiatives. At least five of the nine sites were currently or sequentially undergoing an ERP or MRP implementation. One interviewee said that their management viewed PDM in the following way: "We know we need [a PDM] but we're not sure why, and we don't stand behind it enough to fund it."

Similarly, nine out of seventeen individual program respondents felt that their efforts were adequately supported by management. Some cited middle-management resistance, while others simply ignored the changes taking place as long as they could.

Unfortunately, in some cases, site implementation teams did a poor job the first time around in coming through on their schedule estimates or capability promises. Only two out of nine sites made their planned schedules (which were likely already extended beyond the original schedule) for the implementations focused on in this study. Management, in some cases, lost interest in the project due to previous similar efforts that had been disappointing. The consequence was that the management was then disposed to listen to corporate and any new mandates (such as implementing a standard ERP) rather than support the efforts currently being driven at the site.

5.7.4 Process For Learning

Given the lean principle of continuous improvement, and arguably Six Sigma practices, it seems reasonable to expect that the eight sites that claim to practice Lean and/or 6Sigma would have a standard process to capture lessons learned. Based on the magnitude of these implementations and the changes typically required from a process perspective, the ability to learn and evolve the approach to such initiatives would be invaluable.

Out of the nine sites, only three could say they have a standardized process in place to capture lessons learned and feed them back into the system. Two of the six that do not have a standard process did admit to having an informal method to capture lessons, one case being an individual effort. Situations where a standard process is not enforced makes it more difficult to roll changes based on any lessons learned into subsequent efforts implementation. A majority of the interviewees could cite ways in which changes had occurred based on past experience but they tended to be limited due to the lack of knowledge capture.

Much of the "learning curve" can be observed based on how implementations have changed over time, such as the take aways in section 5.7.1e).

5.8 *Extent of PDM Capabilities*

Based on site and program characteristics and levels of experience, the nine sites have each reached different levels of capability and integration with their PDM implementations. Two sites have effectively involved the entire organization, while the rest are varied as they continue to develop capability and extend it across the user community. All of them are continuing to make improvements and changes in their solution and implementation methods.

5.8.1 The Body of Users

a) PDM Access

When collecting information on who uses PDM within the organizations, the users were grouped into two types: data creators, and data inquirers. The first group has the ability and/or need to both create data and access it whereas the second group typically only accesses it (and therefore has more limited authorization). In all of the organizations studied, engineering represents the largest user group of the system.

Each program was asked how many employees use the PDM. The number per functional group and how many were creators verses inquirers was noted. The data in the following two figures are extremely sparse because it was difficult to get accurate counts on, but the data that was collected represents eight different programs from seven different sites.

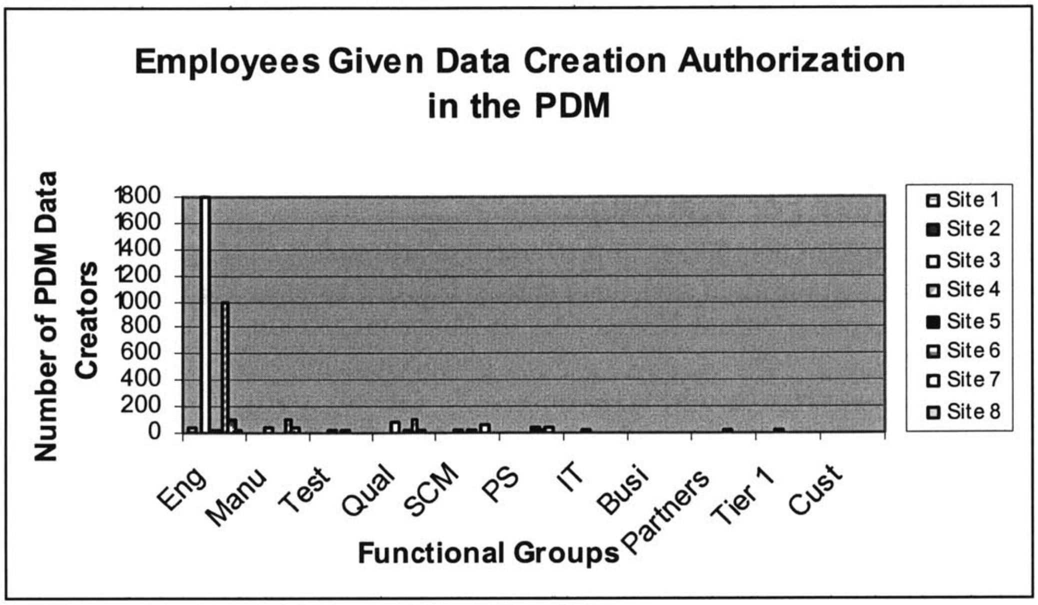

Figure 12: For eight sites, this shows the number of employees for a given function that have the authorization to create data in their PDM.

Figure 12 represents the number of PDM users that have the permissions to both create and utilize or access resident data. As noted earlier, the highest number of users resides in the engineering part of the organization. The users in the other groups, as you move further downstream in the lifecycle and into enterprise-level functions (such as business), begins to dwindle. Examing the data in Figure 13, there is a tendency to limit the capabilities of those downstream users by only giving them inquirer privileges. There is fewer data in the second chart because some of the sites do not yet distinguish between the two classifications of groups. In those cases, anyone who uses the PDM for either reason has the ability to do both, even if they do not utilize it.

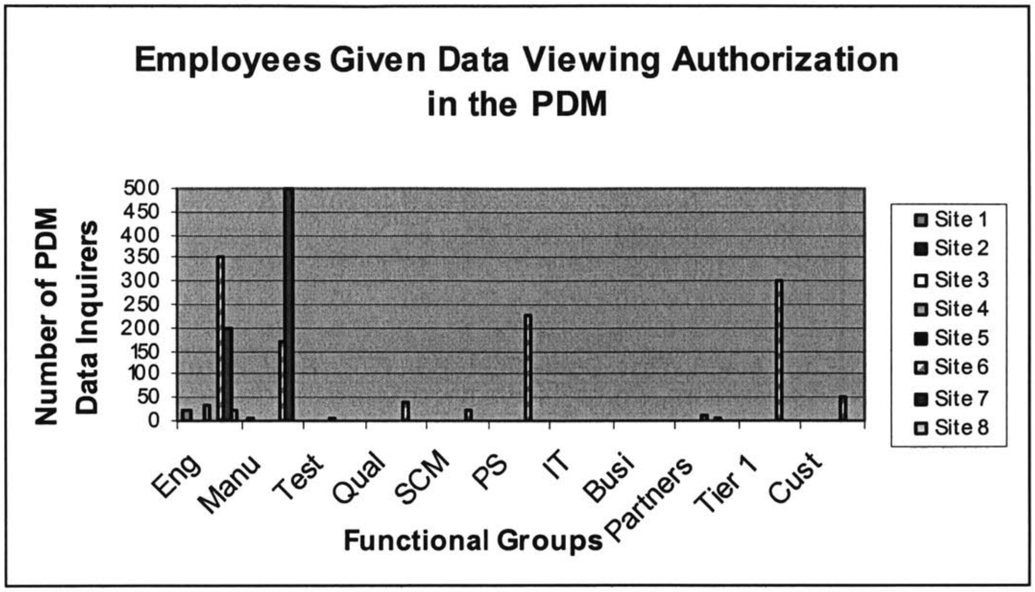

Figure 13: Similar to Figure 13, this shows the number of employees that have the authorization to access data within the PDM.

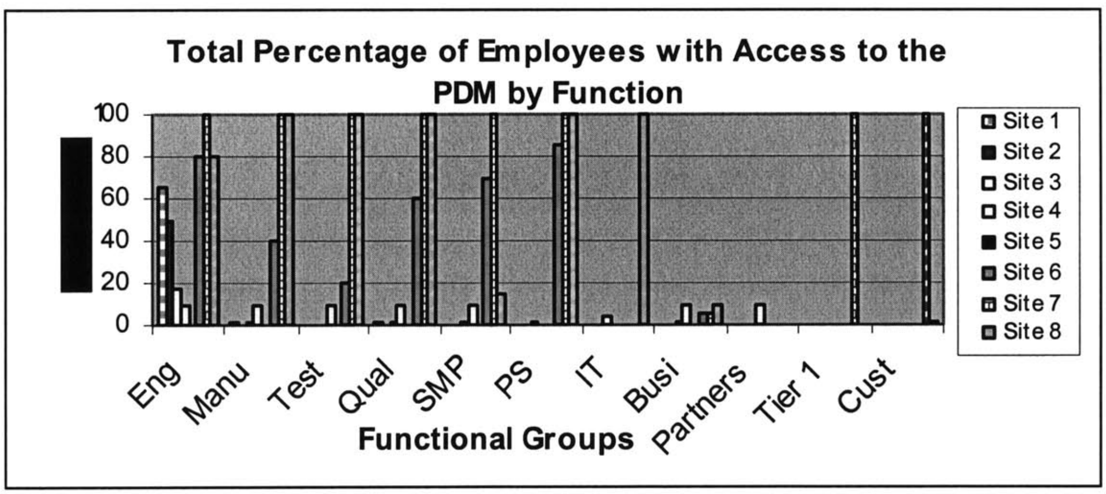

Figure 14: This is the percentage of personnel in a given function that use the PDM, on a per-site basis.

Figure 14 shows, within functional groups, the percentage of personnel within that group that is considered a user of the PDM. As you can see, site 7 has been very successful at providing access to the majority of its lifecycle, including its top tier of suppliers and customers. The program represented by site six also has breadth across its lifecycle regarding PDM access. For most programs, however, it is not desired or necessary to give all employees access to the PDM.

The following table shows the data used for Figure 12 through Figure 14. Data was only obtained from eight of the nine sites for this particular set of questions. Blank cells indicated that no data was collected.

Table 4: The number and types of users of the PDM organized by function.

Data Creaters	Eng	Manu	Test	Qual	SCM	PS	IT	Busi	Partner	Tier 1	Cust
Site 1	47	8	0	0	0	0	0	0	0	0	0
Site 2	5	0	0	0	0	0	1	0	0	0	0
Site 3	1800	50	12	80	30	0	30	10	0	25	10
Site 4	16	0	0	5	10	0	0	5	4	0	0
Site 5	30	0	20	20	15	50	4	4	30	0	0
Site 6	1000	100		100	0	15	0	10	0	0	0
Site 7	100	50	10	25	60	40	0	5	0	0	0
Site 8	25	4	5	4	3	1	0	0	0	0	0
Data Inquirers	**Eng**	**Manu**	**Test**	**Qual**	**SCM**	**PS**	**IT**	**Busi**	**Partner**	**Tier 1**	**Cust**
Site 1	20	4	0	1	0	0	0	0	0	0	0
Site 2	0	0	0	0	0	0	0	0	0	0	0
Site 3	0	0	0	0	0	0	0	0	0	0	0
Site 4	32	0	5	0	0	0	0	0	10	0	0
Site 5	0	0	0	0	0	0	0	0	0	0	0
Site 6	350	170		40	25	225	0	0	4	300	50
Site 7	200	500					0				
Site 8	25	0	0	0	0	1	1	2	0	0	1
Total % Pop	**Eng**	**Manu**	**Test**	**Qual**	**SCM**	**PS**	**IT**	**Busi**	**Partner**	**Tier 1**	**Cust**
Site 1	66	2	0	2	0	0	0	0	0	0	0
Site 2	50	0	0	0	0	0	0	0	0	0	0
Site 3	18	1		1	1.2	1	3.75	1	0		
Site 4	10	10	10	10	10	0	0	10	10	0	0
Site 5	0	0	0	0	0	0	0	0	0	0	0
Site 6	80	40	20	60	70	85	0	5			
Site 7	100	100	100	100	100	100	0	5		100	100
Site 8	80	100	100	100	15	100	100	10	0	0	2

b) User Satisfaction

Those interviewed from a site level were asked how well they thought user expectations were met. Of the seven responses, six were mixed with positive and negative reactions, and the seventh said that user expectations were not met at all. When asked what the cause was, the following reasons were identified.

In some instances, user expectations had either been set too high or just misguided. When the new system was implemented, users tended to be disappointed, either because the system did respond the way they were expecting it to, or because something about it did not work as well as the legacy tool they were accustomed to. In other cases, the system "worked" but still had "a ways to go to be most useful to users." A couple of the sites had difficulty providing responsiveness so users saw it as holding them back from being able to perform their tasks.

Another trend that has affected the way the tools are presented to the users is related to organizations trying to standardized processes. Most users are accustomed to tools that have been customized to their program or specific functionality over the years. Standardization often causes additional or unnecessary steps to perform the same actions as before because it is meeting the needs of several different stakeholders simultaneously. Users typically do not see or realize any resulting benefits that are beyond the design phase where the data is being originated.

The biggest uproar from the users is typically when the graphical user interface (GUI) has changed significantly than what they were used to. This is to be expected and unfortunately requires customizations to make the OTB GUI look and function as a legacy tool. This is especially true when considering that new capability and options have been added. Hence, as described in section 5.6.4, many of the sites have spent considerable time customizing the user interfaces.

5.8.2 Other Data Management-Related Capabilities

a) Internally- verses Externally-Generated Product Data

The sites interviewed internally generated minimally 40% of the product data they are responsible for managing. Most of them claimed to generate 70% or more. This implies that most sites have supplier product data being delivered to them. The sites were asked what was done with supplier data and their answers were somewhat surprising. Half of the sites did not have a standard way of handling the data, but indicated that determining that process was a priority. Some are scanning and storing it in the PDM, whether or not they think that is where it should rightfully reside. Others are using a non-PDM system to manage it. One interviewee said that they had "As many ways of handling the data as we have of supplier personnel handling it. [It is] dependent on the program, and a host of [other] things."

b) Methods for Collaboration

In order to determine what kind of role the PDM played in collaboration, the interviewees were asked to identify all of the methods used for collaboration. Each of the eight responses listed PDM among others and expected it to be used in at least one of three ways: internally between users to gather files; externally by other sites, customers and suppliers; to enable the use of a vendor COTS product designed specifically for collaboration.

Table 5: The frequency that a given method of collaboration was cited.

	Paper	E-mail	PDM	PDM Vendor Tool	Other COTS	HG
Frequency	3	4	8	4	4	?

Table 5 summarizes the site responses, allowing a site to have more than one response.

c) Legacy Tool Reduction

The sites' abilities to reduce the dependence on legacy IT systems and retire them depends on whether they are able to remove all critical product data from the legacy system and transfer it to the PDM. One site was successful in shutting all relative legacy systems (those with similar capabilities to the PDM) while another has been unable to shut down any of its relative legacy systems due to the vast number of programs that still have data residing on it.

Depending on where ownership of the legacy systems lie, there are sometimes battles over "my system" where an owner is not willing to retire their system. Deciding how to manage the elimination of legacy systems is an important consideration. A common thread within the site stories was that when the continued use of legacy systems was allowed, the users would continue to use them at all costs. Given the standard business case for PDM, shutting down legacy systems when at all possible is important to reduce non-standard effects and streamline the data flow within the company.

5.9 *IT Tools Utilized for Program Needs*

As addressed in the opening chapter, data management has progressed dramatically over the last decade. With the push for better product data management and better tools, there are questions arising over who should own the data and with what tools they should be managed. The following data illustrate how nineteen programs across eight different company sites are supporting both functional data needs and management of specific data elements. The same data is not presented from a site perspective because there is little consistency across how programs in a given site manage data.

5.9.1 Functional Tools

Every program was asked what type of IT tool was being used for seven different common functionalities: vaulting, document release, product structure, collaboration, workflow management, visualization, and change management. These seven areas were chosen based on what PDM is typically marketed to do.

Figure 15 is a snapshot of how the programs interviewed are currently enabling each functionality. The trend follows what one might expect based on the evolution of PDM and the history of data management. The more traditional design engineering functions use a PDM heavily whereas the more recently available technologies rely heavily on other types of tools beyond PDM.

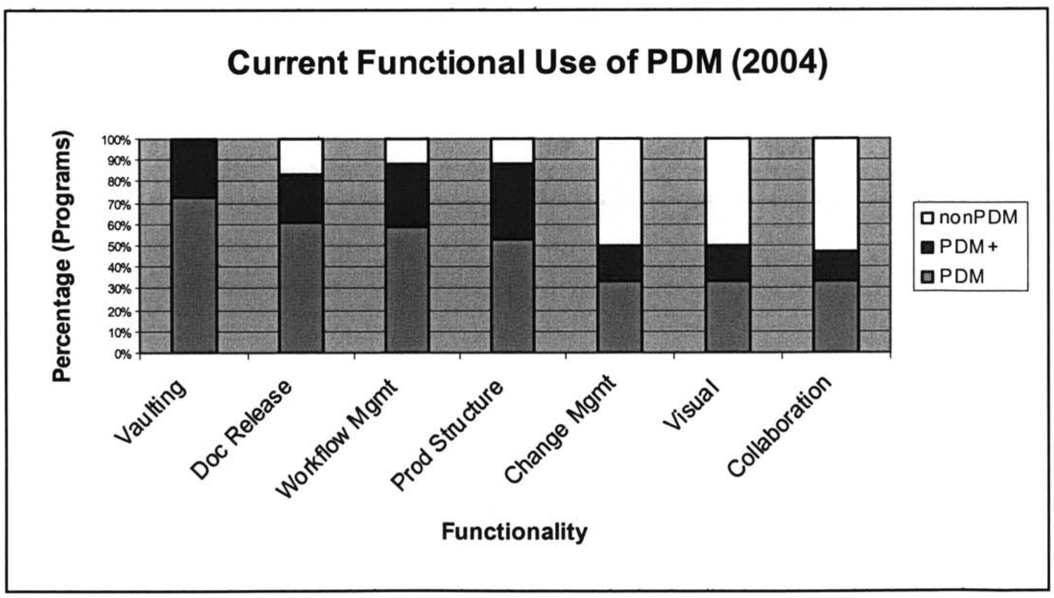

Figure 15: Data based on site responses regarding seven common "capabilities" for which PDM is typically marketed.

In the legend, PDM+ means that a second tool in addition to PDM is being used for the same functional reasons. It does not imply that they are both managing the same components or data however. NonPDM refers to the use of some other tool whether it is a different COTS or a homegrown tool. When program interviewees responded, they were told that "PDM" as a response was to be based on their product's core functionality. If they were using an additional tool by the same vendor that could easily be integrated into the PDM, often referred to as a "bolt-on", those were treated as a COTS tool, or "nonPDM".

In the graph, the functions are ordered based on the frequency that a PDM is used with vaulting having the highest frequency. This is expected given that PDMs have historically been used for that purpose. Document release, workflow management, and product structure follow pretty closely with few exceptions of being managed fully without PDM. These three functionalities are typically marketed as core PDM capability by the vendors and are therefore, typically going to be the main tool of choice for any company currently using a PDM. The exceptions are typically legacy programs that are using PDM in some way, but are not fully using the PDM capability due to an approaching retirement phase for example.

The last three functionalities, change management, visualization, and collaboration show a less frequent use of PDM. The definition for visualization and collaboration was not strict, allowing interviewees to answer based on their program's definition. This means some programs using a PDM to do collaboration, for example, might have a very different capability than a program that had purchased an additional tool for that particular functionality. For those who do not use a PDM for their change management capability, the most common tool being used is a homegrown legacy tool. For visualization and collaboration, the most common response was a COTS tool. In some cases this was an independent tool, and in others, it was an 'additional capability' provided by a separate COTS but integrated into the PDM.

5.9.2 Data Element Management

The programs were asked, for eighteen different types of data, what type of tool they were using to manage them. The data of interest were identified during the research workshop. Interviewees were provided with four possible responses as to what was used to manage the data: PDM, ERP (or similar tool), configuration managed otherwise (CM), not configuration managed (non-CM). They were allowed to provide a combination answer when more than one answer was appropriate.

The results are presented in two ways. The first figure shows, at the time of data collection, what tools are being used to manage specific types of data. Knowing that this would not fully capture what was being accomplished, or changing, through the PDM implementations, a second set of answers was requested. For a program that had already undergone their PDM transition, it was asked how the data was previously managed. For those that were within a year of upgrading or transitioning to a different PDM, they were asked for how they were planning to manage the data. For any program that had been cancelled, only its state of data management at the time it was cancelled was recorded.

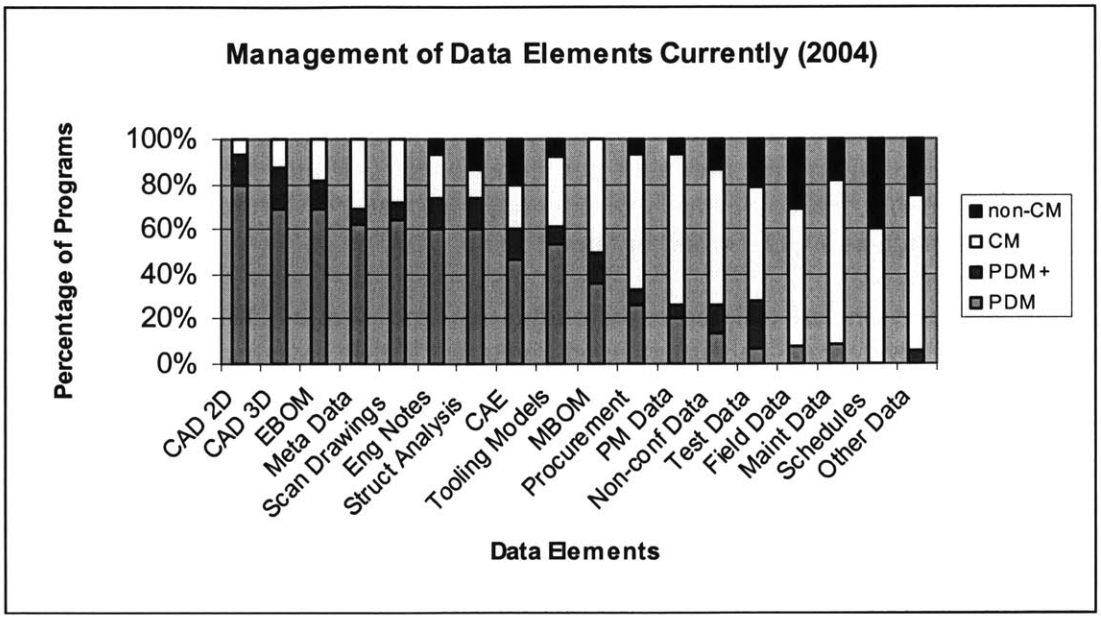

Figure 16: The percentage of programs that used a given method to manage product data at the time of data collection.

Similar to the data collection in Figure 15, the respondents were given a limited set of responses. These included the major business systems such as ERP, MRP, and PDM, and COTS otherwise. The data are graphed in a way that is in reducing order of PDM use. By inspection, those data elements more historically thought of as engineering and "configuration controlled" data lie to the left side, while less design-centric data lies to the right. Half of the programs interviewed appear to be using PDM to manage their MBOM in some way.

Seeing the current state of PDM use based on the companies that were visited is interesting, but it is more insightful to look at how the use of PDM is changing, based on those currently undergoing PDM implementations. The data in Figure 17 and Figure 18 were aggregated by using the current state, and either a past or future state depending on whether the program being questioned had already undergone its most pending PDM change or was expecting to. If a program had already undergone its implementation, then past information would have been collected, as well as current which falls under the future state. If a program was waiting, then its current information would serve as the past, and its expected changes in data management would represent the future.

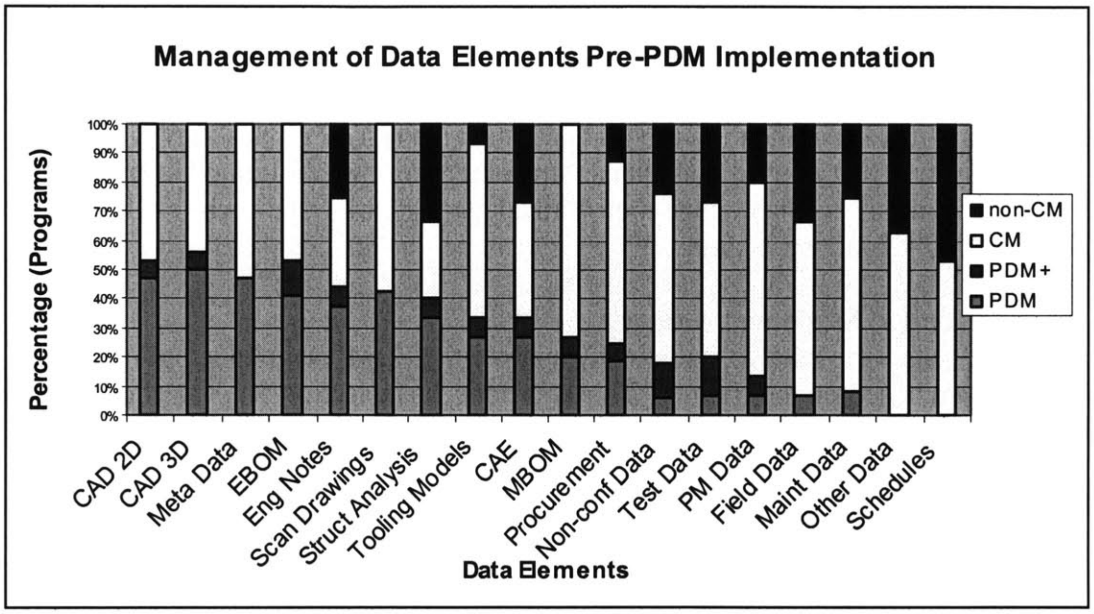

Figure 17: The percentage of programs that used a given method to manage product data before their most recent PDM implementations.

Using this method, Figure 17 and Figure 18 give some indication of how the trend in data management, regarding PDM, is moving. The same combination of responses seen in Figure 18 was used here.

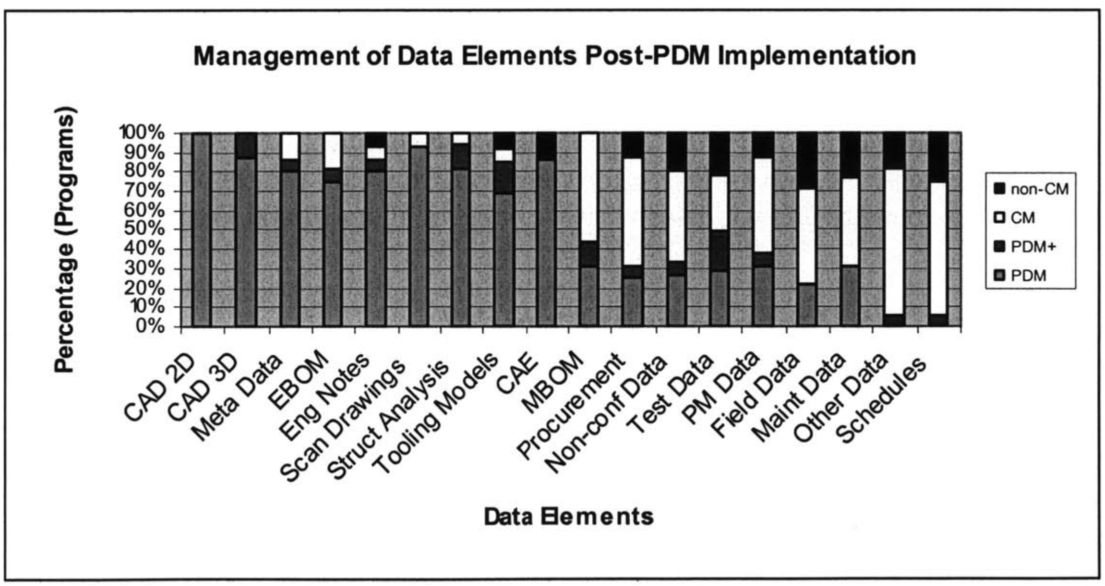

Figure 18: The percentage of programs that are or will use a given method to manage product data after their most recent PDM implementations are complete.

It is clear that the use of PDM is increasing as PDM implementations are occurring. We would expect this. It is interesting, in Figure 18, to note the distinct drop in PDM use at the MBOM stage and after. With the exception of tooling models in some cases, all of the data to the left of the MBOM is traditionally considered pre-manufacturing, or "design engineering" data.

Everything to the right of MBOM is downstream of the design engineering process or at a higher level, such as schedule data. It would be interesting to understand why certain companies are using PDM to manage seemingly obscure pieces of data with a PDM. Is it because they are a small supplier and it was simple to put in that data with the rest? Perhaps they were shutting down a legacy system that housed that data among others so it was migrated into PDM with the rest? Seven of the nine sites had experience with a legacy PDM system while all of them were undertaking new development efforts.

a) Limited Statistical Analysis

Non-parametric tests were used to statistically analyze the PDM-usage in support of the conclusions drawn based on the figures. This was done, as in section 5.5.3 to show statistical significance rather than draw conclusions based on what the charts seemed to reveal.

The two hypotheses tested were:

1. Is there a difference in how much product data is being managed by a PDM between prime and supplier companies?
2. Is there a difference in how many data elements are managed before PDM implementations and after?

A Kruskal-Wallis independence test was used to determine if the prime and supplier companies could be considered statistically different based on how often they used PDM verses other tools or methods to manage certain types of data. The results indicated no difference between the prime and supplier company type ($p = .248$). This implies that PDM is being used to a similar extent across the enterprise. This does not imply that the same level of integration has occurred throughout the industry

A Wilcoxon Signed-Rank test was used to compare how programs managed data before their current PDM implementation and after. There was strong significance ($p < .0001$) indicating that to an unknown extent, the site's PDM efforts are increasing the programs' use of that tool to manage data. This restates and validates what we believe Figure 17 and Figure 18 indicate.

5.10 *Product Data Management Maturity*

An interesting outcome that was not expected from the surveys is where the majority of data management capability lies within the consortium. Four diagnostic statements intended to measure PDM maturity were presented at both the supplier and site level. The four statements were:

1. Integration of product data across the product lifecycle
2. Extent of supplier/partner integration
3. Management of workflow electronically throughout the product lifecycle
4. Integration/compatibility with current systems/applications

Each statement was accompanied by five levels of maturity, ordered from least (=1) to greatest (=5), and each respondent ranked the level at which their site was at overall. Letters 'A' through 'E' represent suppliers and 'F' through 'I' represent prime companies (with the FFRDC grouped with suppliers based on its characteristics and needs). A copy of the specific scale indicators used can be seen in Appendix A.

5.10.1 Individual Question Results

a) Q1: Integration of product data across the product lifecycle

This question was attempting to address how seamlessly the flow of product data had been connected throughout the enterprise. Indicators included where data resided, i.e. whether in several legacy systems or a few, and how those were connected with PDM. It also addressed how easily product data was being shared with partners, both nationally and internationally, and suppliers.

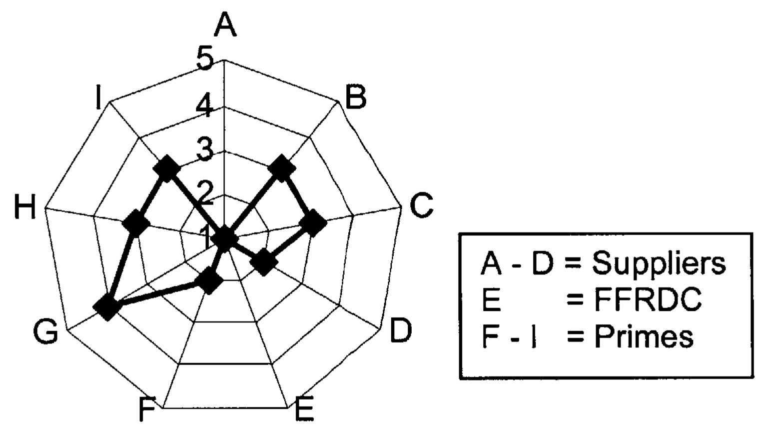

Figure 19: Site responses to the first PDM Maturity question ranging from 1 to 4.

The graph indicates some difference between the supplier companies and the prime companies' integration across the lifecycle. Site A and E have the lowest possible capability, while G is the furthest along.

b) Q2: Extent of supplier/partner integration

The second statement was a diagnostic of how well sites are able to share product data specifically with external entities. Indicators of this included whether data is shared via paper or digitally, and to what level of the supply chain the capability extended. It did not require that this sharing be done necessarily by a PDM.

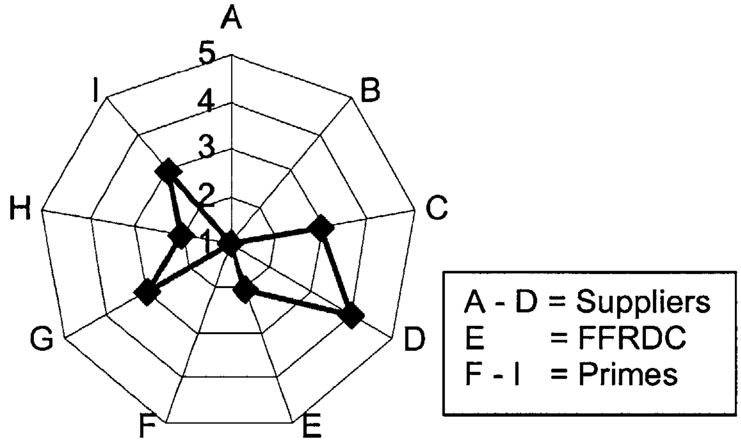

Figure 20: Site responses to the second PDM Maturity question ranging from 1 to 4.

The responses to this question yield a different picture, due to the question. For suppliers, it was modified somewhat to include their customer, as they are part of the supply chain. For the prime companies, the supply chain is typically very extensive and either has very diverse capabilities, or lacks many of the digitally advanced capabilities.

c) Q3: Management of workflow electronically throughout the product lifecycle

This statement is meant to diagnose how many of the processes have actually been implemented into the PDM and associated systems. Indicators included if processes had been standardized, whether processes within and across functional groups (e.g. engineering, manufacturing) had been automated, and if externally linked processes had been electronically enabled.

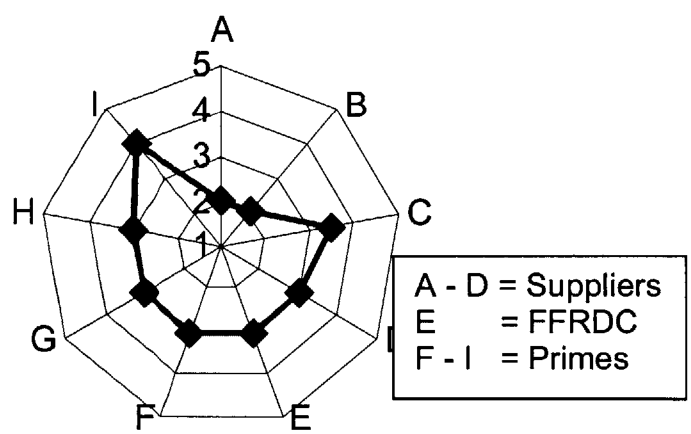

Figure 21: Site responses to the third PDM Maturity question ranging from 2 to 4.

The results indicate that a majority of the sites interviewed have made similar progress in this area. The two low-capability exceptions indicate that very little, if any, of the workflow has been completely automated. In Company I the internally, cross-functional processes are automated, as well as some minimal external processes.

d) Q4: Integration/compatibility with current systems/applications

The fourth and final statement was intended to measure how successful a site had been at minimizing its business IT systems and integrating them together. The scale factors addressed whether product data was all handled electronically between the systems, or whether a person had to intervene to make transfers and conversions. It also touched on whether product data was being replicated, and again on how a site's systems interacted with external entities' systems, regarding the level of interfacing or integration.

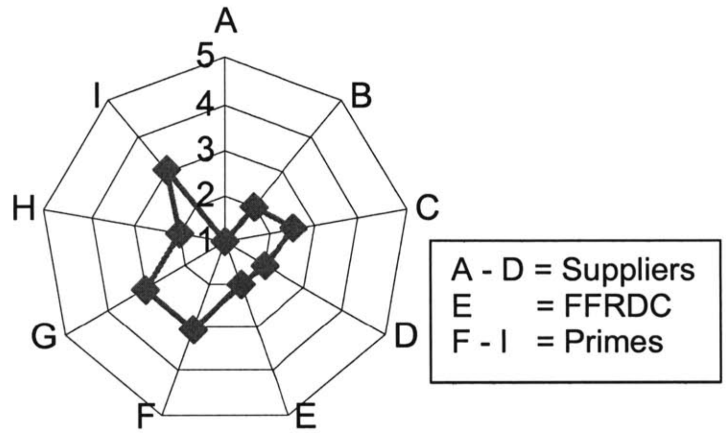

Figure 22: Site responses to the fourth PDM Maturity question ranging from 1 to 3.

The results from this question show, in general, slightly more capability with the prime companies, but overall no one has succeeded fully yet by eliminating replicated data and any manual entries that must be made into the systems. Both of these indicators are important from the standpoint of simplifying and streamlining data flow.

5.10.2 Combined Maturity Results

When overlaid, the results from the four statements present a representation of how the nine sites compared overall

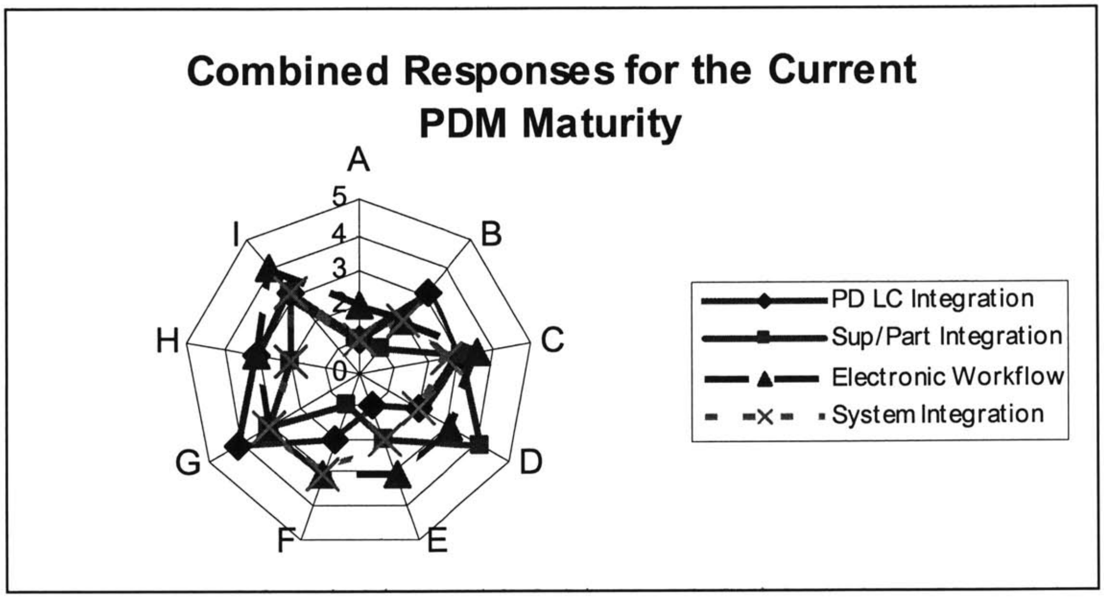

Figure 23: A combined view of the site responses to each of the four PDM Maturity questions based on their "current state" maturity.

Based on the four individual representations, there are certain areas where capability tends to be higher in one company type verses the other. There are also areas, such as automated workflow, where all nine sites have not made as much progress. It is hard to tell, by looking at the combined results, whether there is much difference in the two groupings (A-E and F-I) or not. Figure 24, below, is a graph of each sites average score over the four areas. It indicates that a slightly higher capability overall resides in the prime companies, validating Abramovici's claim that PDM/PLM system penetration is much lower in smaller companies (AS 2003; Anderson 1995).

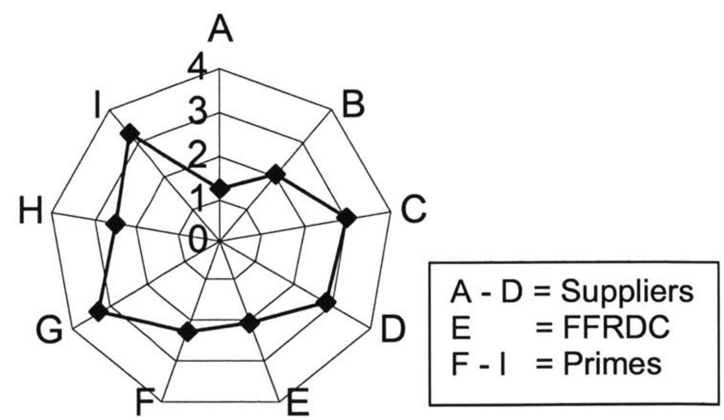

Figure 24: An average of the four responses from each site to the PDM Maturity questions ranging from 1 to 3.5.

5.10.3 Desired Maturity Results

When indicating their current state of capability in the four areas, site interviewees were also asked to indicate what level of capability they were aiming for in the near future. In most cases, the fourth or fifth level of capability was desired. There were some interviewees who indicated that the most ideal capability was not feasible in the near timeframe. Others were probably somewhat optimistic in their near-term goals. In either case, the data indicates that the desire for capability commonly associated with PDMs has not been reached and companies are actively pursuing further gains.

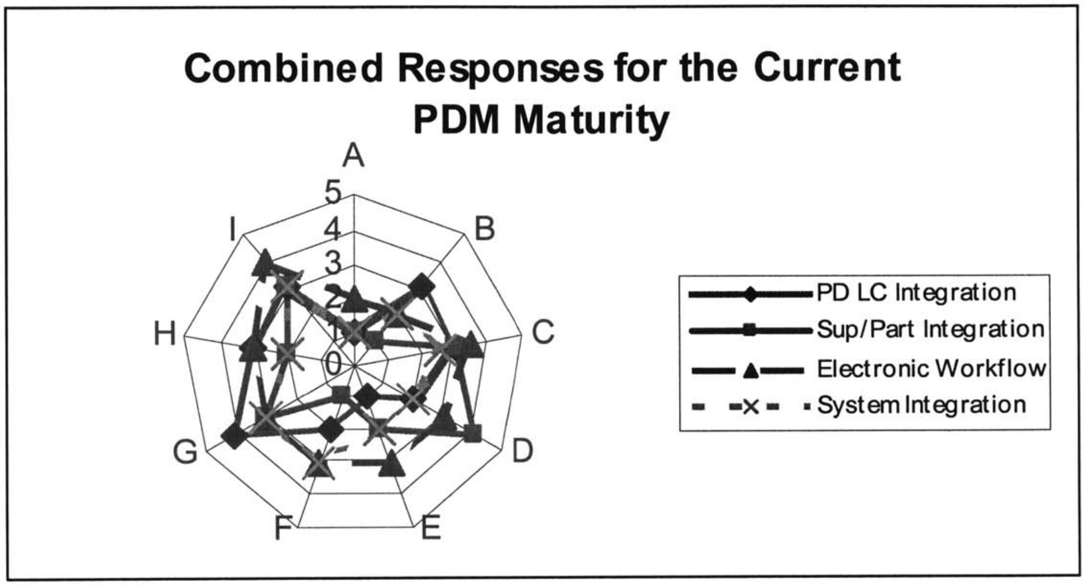

Figure 25: The combination of each site's four "desired state" responses to the PDM Maturity questions.

Also, given that prime companies tend to have more complicated supplier networks, legacy systems, and larger volumes of data, it is understandable that it might take longer to accomplish standardized and integrated processes, systems and networks.

5.11 *Major Challenges*

The data presented in section 5.9 illustrates the functionality and type of data that programs are using and managing with their PDM systems. From a general perspective based on what programs initially had planned for and expected verses what was actually accomplished, most of the sites missed their original target. Even discounting whether they missed their schedule or not, most sites have delivered less functionality than desired or originally intended. When one interviewee was asked for the difference between what was expected and what the actual outcome was, he replied "Just less functionality at a later date."

There are several reasons why this might, and has, occurred. There are reasons that are controllable from an implementation perspective, such as poor planning or miscommunication. Others however, such as vendor product changes, come unexpectedly and adjustments have to be made for the solution to be delivered at all. Most of the issues may sound technical, but there is as much political back and forth as there is with the technology. Examples of the political challenge include people wanting to protect their current tools or projects and tension between what corporate thinks is best for the company versus local efforts at a given site.

5.11.1 Unexpected Course Changes

a) Shifts in the Tide

In over half of the implementations studied, there were inevitable circumstances that were uncontrollable from a local PDM implementation team perspective. Several times it was due to a shift in either what the vendor was scheduled to release, or when they were scheduled to release it. This would cause the team to have to re-plan their deployment phases and might cause some extra programming and customization in order to still release the needed functionality for the programs on-time. The impacts to schedule and budget became show stoppers.

Something additional emerged from the data as well: there is often a knowledge or communication gap between the PDM team and their management within the site, as well as between the site management and the corporate office. In some cases, local management would change, or make a decision for the site that would affect the PDM team and their schedules or budget for implementation activities. One interviewee said that his new and respected boss "came on and started pushing things we were not ready for such as workflow issues." Another example of this is illustrated in the Space case study in section 6.3.

There seem to be numerous occasions where a PDM team is making progress, and suddenly the corporation decides to implement an ERP system company-wide. The amount of integration required between the two systems is often not immediately realized. In many cases, the teams developing these two business solutions are separate and distinct, making the integration more difficult. The second problem is that attention and resources shift while in mid-development of the PDM. This again results in schedule delays and can cause more pushback from the organization. In some cases from the interviews, such a situation even resulted in changing the implementation approach from being all at once to being phased.

b) Everest Behind the Clouds

Everyone understands and expects there to be problems and difficulties when making such large changes across an organization: its processes, culture, and technological infrastructure. However, in every single site studied, there was a "challenging" portion of the implementation that turned out to be a much larger challenge than anyone expected.

One of the two most commonly underestimated tasks based on the interviews was the data migration portion of the implementation. Over half of the sites said that this took longer than expected. Because migration typically occurs close to the go-live of the implementation, it either causes a major delay in the schedule, or gets done poorly. Doing a poor job of scrubbing and transferring data from one system to another has lasting impacts that some teams have been struggling with several months after they've succeeded with the implementation otherwise.

The second most commonly underestimated barrier is the cultural resistance. Interviewees could not have been more emphatic of the impending doom that can be brought upon any implementation depending on how the user community is approached and managed.

c) Misunderstanding the Technology (a.k.a. Poor Decision Making)

Another struggle that many PDM teams face is when a vendor product does not perform as expected. There were two examples where a decision had been made and several months later, it was decided to abandon that particular solution and seek out one that was more compatible with the company and its needs.

A second common issue was general shortcomings of understanding the limits of what the solution could provide and what amount of development that end product would require. One site admitted to not having certain processes ready when the technology was. Some also submitted challenges in keeping the scope of the project aligned with the set budget and schedule. This became especially difficult when management or the user community would like what they saw (or what others around them were doing) and want more. In some cases, more familiarity with the software bred better decisions in what the final solution should look like. One example of this was shifting from a thick to thin client in order to deliver web services along with the other functionality. Again, misunderstanding the solution has a high potential of impacting the schedule that has been established.

5.11.2 If You Could Do It All Over Again (But Not That You Would...)

When interviewees were asked what they would change based on their experiences with their respective implementations, several answers were given. Some responses were specific to the given deployment such as the way a technical detail was handled. Many of them, however, serve more broadly as warnings and pitfalls to be aware of in future endeavors.

From an overall standpoint, a lack of structure around the PDM development and implementation made it harder to be effective in mitigating problems as they come up. Structure implies accountability, and when there is accountability, fewer problems go unnoticed or unaddressed. One comment to "Run it like a program," speaks to using program management practices that are well-defined and tested. "If we design an airplane, we've got a great process. If we want to share data, we're not as organized." Although there may be some differences, ultimately the PDM implementation has a defined schedule, budget, set of requirements, and deliverable. If it does not, then following through on the proposed implementation becomes much more difficult.

Another set of comments addressed the process question. One of the two main points made was ensuring that the process owners were just that: that they know and understand their processes and are involved in the changes to those processes. The second was to ensure that the process owners and subsequent users of said processes buy-in to what the changes are and why.

Chapter 6. Phase Two Analysis: Case Studies

6.1 *Introduction*

Two companies active in recent and ongoing PDM implementations were visited in order to address the following two questions based on what was learned in phase one of the data collections:

1. What was the initial tool selection process?
2. How are the technology and organization evolving over time?

Both companies, herein referred to as Aero and Space, were part of phase one of the research. The companies are similar in size according to number of employees and have most recently implemented the same vendor tool. Although they both have very strong cultures, they operate with very different management environments and as a result, have approached PDM with different approaches and measures of success.

6.2 *Aero Case Study*

6.2.1 Aero History

Aero has a long history of product innovation in military/defense products. Although it has always been a leader in their core competencies, it has not always performed well financially. One of its first big contracts came in the 1940s as the United States transitioned between the first and second World Wars. Significant knowledge and experience was gained in key applications, leaving Aero with few competitors. Primarily serving the Navy and Marines, large amounts of government dollars were spent developing and purchasing its products, particularly during Vietnam.

As Vietnam came to a close, ending a long period of heavy defense spending, the need for production decreased. Its processes and consequently, manufacturability, became very expensive and Aero's employee base dropped from over 10,000 to as low as 3,500. Although leaders within the organization trying to compensate for the environmental changes, nothing they were doing was making an impact to the bottom line.

By the 1990s, the aerospace industry had begun to recover. Aero's employee base had increased back to 7,000 as some new production initiatives surfaced including upgrades to legacy products. Aero underwent a big merger in the mid-90s that brought on some additional new initiatives. None of these sat well with the culture and capability, however, and were abandoned or divested as separate businesses. A major program was cancelled early in the new millennium at Aero due to changes in customer requirements and the budget. A second major program underwent several hurdles as designers struggled with an advanced, highly complex technology development, putting its future into question.

Typically aerospace products are highly complex and bought in low quantities, contributing to the products' high expense. Add to that a mature company that has gone through several transitions where great technical advances were made only to have the program cancelled due to changing requirements and defense spending cycles. Through these changes, Aero's organization became bogged down in legacy tools and processes. Eventually, Aero became one of the largest profit-loss centers within its corporation and was in danger of being shut down or otherwise eliminated. Due to its valued expertise in the defense sector and the jobs it provided, a political decision was made to not close down the facility. That left the corporation with one option – figure out a way to make Aero a profit center.

At that point, Aero was challenged and required to reduce costs by 20% across the board. Aero's leadership realized that they had to revolutionize the way in which the organization operated – what they chose to manufacture, the processes used over the lifecycle of a product, and how they handled data management and information flows between design, the shop floor, and product support once the product had been delivered.

6.2.2 The Situation That Led to PDM

Max, a well-known and respected program manager at Aero, was asked to lead the site in its transformation efforts. He formed a small team within the company and charged them with finding a technical solution. The direction the team took was influenced by several factors. First, the tool used internally for the design work, where drawings and other product data is first generated, was a common off-the-shelf (COTS) computer-aided design (CAD) tool. The vendor company had been developing a primitive-version product data manager (PDM) that could be used to manage the proprietary CAD files. The two tools, developed by the same vendor, worked seamlessly together. Second, there was a growing trend in the industry to adopt PDMs as the solution to managing increasingly complex CAD data. Several companies had been doing it internally with homegrown systems, and vendors had begun to fill the gap and create more sophisticated tools.

The leadership at Aero also looked outside of the facility, benchmarking what was being done in other companies in aerospace as well as other industries. They learned that another site within the corporation was busy developing advanced product design tools and processes. This forward-thinking group had been working on pushing the envelope regarding product design and modeling, and also had experience with a legacy PDM system that they had in place.

Collaborative thinking between Aero's leadership and the sister site brought focus to a key piece of the product data puzzle that lay central to the organization. There is traditionally a bill of material (BOM) representing a product at every point during its lifecycle, whether it is the as-designed (engineering bill of material - EBOM), as-built (manufacturing bill of material - MBOM), as-supported (sustainment bill of material SBOM), et cetera. In most cases, companies will treat these BOMs separately even though they expect them to be perfectly reconcilable representations. Management of the BOM is connected to every other process within the lifecycle, and therefore can/does impact the bottom line through both cost and schedule. Aero's inability to manage their BOM accurately or effectively meant that they could not manage the cost of the product. Starting with the designers, all the way through delivery from the shop floor, there was no effective tracking method to understand the cost drivers, or recognize what could be done about it. The team identified the BOM as the place they needed to make the necessary impact.

As the team researched their options, they were sold on the philosophy and solution architecture choices being driven by their counterparts within the corporation. Moving forward in changing how the BOM was managed at Aero sounds simplistic until you realize the far-reaching implications. The solution was not purely a new IT system, or a few process changes. Undertaking this change and doing it right meant overhauling the IT infrastructure, overhauling the processes and interfaces within engineering, and most challenging, addressing the culture in changing the organization. The solution that Aero fashioned did more than just BOM management. It connected across functions internally as well as across the supply base and customers throughout the lifecycle.

6.2.3 Transforming a Non-Profiting Enterprise

It is not everyday that a newcomer can walk in to a company, announce impacting changes, and then not only follow through on them, but do it in a way that leverages the culture and empowers the organization. The new leadership at Aero, due in large part to its management support, has accomplished just that. However, it was not accomplished without its share of battle scars. The changes about to take place would address organizational issues such as process inconsistencies and inefficiencies, non-standard information flows, and in some ways, the silo effect between functions that is common in aerospace companies. The other major change was going to be the information technology that employees used day to day. The implementation of a new product data management system, part of the BOM solution, was going to impact a majority of the engineers, a significant portion of the shop floor, and eventually those downstream in quality and product support. Change, as expected, was not a popular idea at Aero. The cultural push back that Aero's team was about to encounter could not have been anticipated.

a) Winning Over the PDM Working Group

Two experienced employees from the sister site were transferred to Aero in order to lead the solution development and deployment. Given the dire situation at Aero, their efforts were blessed with a relatively supportive budget. With money less of a concern, the "new guys'" first challenge was to convince the group within Aero who had been working their own solution that a different approach was needed. A trade study comparing vendor offerings provided a backdrop for why the currently selected solution fell short of the new requirements. The "internal" team was given some authority in the process of setting up and running the trade study so that when the results emerged, they had no choice but to buy in and bite the bullet.

Once differences between the teams had been addressed and ironed out, the newly integrated team then faced its next challenge: preparing the culture, organization, and technical solution. Overall, the site had a finite number of major programs that would define subsequent deployments of the solution, with improvements made along the way.

Based on the author's experience across the aerospace companies studied, there was a fairly consistent methodology used to prepare for similar engineering/IT initiatives. Typically companies addressed their processes in some way, spent time cleaning and migrating data from legacy systems, ran a pilot of the software, trained the users, and then rolled out the new system. With such a process, there is an expectation from management to have a budget and schedule.

Unfortunately, the budget is usually restrictive and the schedule is optimistic, without building in allowances for unexpected setbacks. The management brought in to lead the implementation at Aero had experience from activities they were involved with before joining the Aero team. They knew that the schedules created would not hold up over time and intentionally created opportunities, and the expectation, to mitigate schedule changes. Looking back over the four-year implementation period, however, the team even now realizes that regardless of planning and experience, there will continue to be unexpected challenges.

b) Challenging the Organization

Many experienced practitioners will tell you up front that the cultural resistance to change will be your toughest barrier. The weight of that wisdom, however, is not felt until it is personally experienced. Some employees at Aero were aware that changes were necessary for the company to survive. Many others, however, were convinced that whether or not they did things differently, they were not in any danger of losing their jobs. After all, they were part of a big company with specific, necessary products that the US government relied on.

The implementation team was successful at getting the user community involved in developing requirements and processes; an imperative step in creating an appropriate solution for the enterprise. They conducted meetings where they would "deep dive" into a particular process. This required detailing the process, learning it, evaluating it, and then making changes to it that the affected users could agree to. These meetings also doubled as a chance for the implementation team to communicate the changes that would be taking place to the users, which facilitated getting buy-in from the user community. This process was conducted without the use of the vendor consultants. They were involved peripherally until it was time to prepare the software solution for implementation.

The next step requiring user involvement was getting the users trained on the system. For the first implementation, Aero chose to train individual functions serially, as they rolled out the new tool to the programs. This proved difficult due to the need to synchronize the legacy systems with the new system, as well as having to train while simultaneously handling user issues. The strategy changed for the next roll-out, training everyone together and turning the program loose all at once on the new system. This allowed the team to handle user resistance all at once because everyone was forced to transition at the same time. A second change made from the first roll-out was to perform training as close to the roll-out as possible. They learned that when users were unable to put the training to immediate use, they quickly forgot most of what was taught.

A third, hard, lesson was that there will always be non-believers. Although about 66% made it to some training before one of the program implementations, that did not guarantee their belief in the coming system and, consequently, they often did not take the training seriously. In most cases, greater than half of those trained were retrained and hand-held over an average of four months before the support team could be reduced and move on to other things. As an example, there was a specific IPT during one of the implementations whose leadership was not convinced of the coming changes and therefore did not enforce his team to attend training. Although the implementation team tried to schedule them for training and work with them, they continued to resist. On Monday morning, after the system turnover, the IPT could no longer log into their old system and they were helpless. At that point, the implementation team had to start over with them, along with those who did not learn anything from training in the first round.

There are many other sources of cultural resistance, especially when it comes to changes that involve information technology. Some of these have to do with the age of users, as well as the changing processes that always seem less inefficient than the old because they are different and therefore have to be learned. In the case of PDM, a particular one is the "my data" syndrome. PDM changes the way that data is controlled and managed. Many engineers do not want someone else to have unlimited access to what they have created and are accustomed to having control over. There is some resistance in releasing said data to a system, as supposed to allowing them to be the gatekeeper of the data. All of these issues will be encountered for any similar undertaking, and have to be worked through. Gaining buy-in is key, as well as putting the right mechanisms in place to enable the friendliest transition for users. This comes down to a well-thought out and implemented solution and a strong user support team that can get problems taken care of quickly and effectively, as well as empower the users to help themselves and each other in learning the new system.

c) Preparing the Technical Solution

Aero was successful in some of its initial key decisions regarding where to place leadership over the project and how to confront the established processes. The first step taken that made for a comparably successful implementation was to realize that implementing a PDM system in an engineering environment should be an engineering-led project. In many cases, companies leave this responsibility to their IT department due to it including new IT. This leads to a solution that typically has very little to do with the engineering processes and data that need to be considered and managed, and more to do with what the latest software release is capable of. This is especially significant when one realizes that the current software offerings are not always well-aligned with aerospace and defense processes.

Aero utilized expertise from both the IT and engineering organizations. They instituted the project within the lean engineering organization, where most of their "processes and tools" development takes place for the same reason. It relied upon the IT organization to implement the software requirements and work on the interfaces for users and between systems. Additional team members included representatives from each program being addressed, an important component for establishing buy-in and having the programs participate in the process development and deployment. The team knew that meeting its internal customers' needs - the users of the system - was imperative to the success of the implementation.

Aero had enough internal IT expertise that it did not require a large part of the developed solution to be carried by vendor consultants. This helped them to make internal process changes and contributed to reducing the tendency of a "tool-driven" solution, rather than a "process-driven" solution. They still encountered imbalances between what the vendor solution said it could do verses how it actually operated in a production environment, such as its ability to integrate more than one CAD type. Additional customization was done for this plus other needs such as specific reporting capabilities.

Another important aspect of Aero's approach was their ability to accept and deploy an "80%" solution, allowing changes to be made after. As discovered by most companies, there are an infinite number of tweaks and upgrades that can be made, but priority on the real needs is an important decision that must be made. Aero ensured that at the time of roll-out the users would no longer have any need to use their legacy data systems. It also ensured that, with some bumps, the users of the system would be able to perform their jobs and program productivity would not be crippled. Minimum impact to the program was one of the highest priorities, and is typically the hardest to accomplish. This put a large responsibility on the user support team. The team was staffed heavily and a fairly standard process was established on how to group user requests based on their criticality and how easy there were to resolve.

Along with Aero's success, the team also had some hard lessons along the way. As alluded to earlier, the cultural pushback was very strong. Even with the support provided through the engineering organization and implementation team, there were pockets of users who refused to accept the system as long as they could get away with it. There were some users who, when given the opportunity, "grandfathered" in as much design work as possible to avoid using the system. Users also created workarounds for the system whenever possible rather than report a problem and have it fixed more effectively. One way that Aero encouraged use of the PDM system was to incorporate doing so as one of the goals in the employee's monthly meetings with their supervisor. This gave the employees initiative to do things such as "Store all of my data in [the PDM system]."

The challenges posed by legacy data systems and data migration were underestimated in many cases by Aero's team. For each implementation, the data situation was different. For the first, much of the effort was spent re-organizing and developing the BOM management before migrating the data to the new system. For the second, it was the challenge of integrating different CAD models and their native programs into the tool. Aero "stayed the course" and was successful in the end at sunsetting its redundant legacy systems, no longer needing to maintain them.

Finally, Aero did not accomplish complete integration as desired and planned with the manufacturing processes and systems. Although they developed a plan that included a larger expansion of the lifecycle than just design engineering, they were unable to complete it in the given timeframe and budget constraints. There is currently a plan to continue the integration with the manufacturing systems once the appropriate funding and support become available.

6.2.4 From Seeing Red to a Sea of Green – A Successful Transition

Over the last five years, Aero has risen to having the highest profit margin within its company division. It has become a more competitive and capable engineering organization due to the changes sustained including having full oversight of its processes. Aero now has transparency throughout a major portion of the product lifecycle that allows management to track and understand cost and schedule drivers for the products. During the PDM transition, the organization also went through a major CAD-tool and design philosophy change. Combining these different efforts meant that the user community would go through more changes at one time. The leadership however, in making it a successful transition, ultimately reduced the amount of change to the employees and their day to day activities over time. Looking back, Aero can take full account of the course that it has taken, and feel good about what it has accomplished and where it stands as an organization.

Aero continues to perfect its solution and make changes as the vendor's capabilities grow with the industry. Realizing the impact and success of its efforts, Aero has taken the opportunity to pass that knowledge and capability on to sister sites, as well as through its supply chain and to its customers. The PDM implementation leadership has been working to integrate geographically separated manufacturing facilities and design centers into the system. This has reduced costs by decreasing wasted time and poor coordination. For example, when a discrepancy arises on the production floor at a remote center, Aero now has the ability to reconcile those differences using visualization and data located within the PDM, instead of hashing it out over the phone. PDM and some of its associated tools have also reduced the need for co-location within buildings on-site.

The knowledge that initially came from a sister site has been iterated on, improved upon, and is now being deployed in small increments back to its origin. Aero personnel that have led the efforts locally are being sent there to train key informants and tackle the challenges that will be faced, both new and old. Those with experience will bring the lessons learned about data migration and user support, while those internal to the culture will be able to manage site-specific challenges that arise.

The greatest benefit that Aero is experiencing from its efforts and investment is the ability to have everyone who interfaces with its product data to do so in a standard, effective way. Aero has provided that capability through a holistically designed solution that utilizes the technology of a PDM to manage product data and processes, providing essential transparency and accountability. With an initiative underway to better connect the PDM to the current manufacturing system, Aero is close to having seamless data flow throughout a major portion of its product lifecycle.

6.2.5 The Future of Aero

Beyond the strides Aero has made in the way the organization operates and the evolution of its IT infrastructure, it has continued to excel as a leader in its expertise. Its R&D organization is one of the strongest within its core competencies and continues to grow. Aero has engaged in several new initiatives and have made it more competitive and desirable to its customers through the changes that have been undergone.

Based on how Aero's performance has improved, there is a potential to take the organization's lessons across the corporation. However, the leadership that was empowered at Aero could be a rare occasion. They were unique based on the financial situation they were in, but they also had one of the toughest cultures to face in a company where no one in the ranks really saw the need for change. Their ability to bring in an outside team, get the leaders within Aero bought in to the solution, and then move through the entire process without stopping in the face of pushback and naysayers is something that rarely happens. There are still many improvements to be made in the processes and links within the IT infrastructure to be tightened and strengthened. Even with these shortcomings, Aero has made a successful transition. There are many lessons to be taken from Aero's experience and following in its shoes will be the challenge.

6.2.6 Aero Case Study Summary

Aero is a business unit within a larger aerospace conglomerate/corporation. Over time, it has been a part of many transitions, acquisitions, mergers, and partnerships, similar to most of our current aerospace companies today. 10 years ago, Aero had allowed its organizational, technical, and cultural infrastructure to take control, hindering it from meeting the needs of a new environment where contracts were shrinking but still had demands for technically elite products. Faced with no other option, Aero's management had to examine itself and take dramatic steps to change the way it operated.

Aero's 10 year journey is viewed from a Lean and IT management perspective as a successful, although ongoing, transformation. It has implemented a product data management infrastructure that has been accepted in most cases by the culture and organization; it defined business processes prior to the selection and deployment of the tool, forcing the tool in many cases to adhere to the business processes; it has enabled the use of product data through a significant portion of the lifecycle, continues to improve reach across the lifecycle and has begun deploying its success to sister sites within the company. Although a successful transition in many respects, Aero continues to fight internal battles for improvement. This story illustrates the turning around of an organization where PDM technology played a big role. The outcomes provide guidance in creating the environment for change and successfully carrying it through.

6.3 *Space Case Study*

6.3.1 Space History

Space is a federally funded research and development center organization within the aerospace community. The range of projects Space takes on is more extensive than that of most aerospace companies. Space typically is involved with projects based on its resources, such as unique facilities and expertise. It has developed and managed aerospace projects, including many subsystems that often accompany these projects. Even more so than other aerospace companies, Space's rate of production is low and therefore its products are expensive. Many of its products only require one to three production models (as supposed to a few hundred), so its needs as an enterprise are different in several ways. It has earned a unique place in the aerospace community while continuing to evolve with similar successes and struggles.

6.3.2 The Situation That Led to PDM

Historically, Space had a functional group given the responsibility of managing its engineering data. This group, called "MED", served as the configuration management powerhouse for all of Space's engineering drawings. Originally a part of the design organization, they were the go-to when anyone on lab wanted the latest version of any controlled drawings. The MED supervisor, having been in his position for many years, was ready to retire in the late 1990s. Management recognized that there were no suitable candidates for his replacement because no one else understood his job or the process that had evolved over the years. In wrestling with how to address this concern, the decision was made to automate the process of managing controlled drawings.

Space concurrently recognized a need for better configuration management (CM) in general. At one time, it was paying three master's-level engineers to sit in a room and reconcile the as-designed bill of materials (BOM) to the as-built BOM. This may not sound too unfamiliar to many accustomed with their own companies' CM organization, but there are two important implications: 1) The ability to reconcile BOMs is very important to an engineering organization's data management capability, and 2) The way that need is being met is often a waste of money and talent in an engineering organization.

Retrospectively, it seems straightforward that switching from an old, manual process to an automated one has many heavy implications. However, the gravity of such change is often overlooked, as was the case for Space. At Space, even though there were rudimentary computer-aided drafting tools, everything was still done on paper. Designers would print out their drawings, walk them over to the analyst or their supervisor, changes would be made on the drawing (which would then become a 'red-line drawing'), and ECRs would be written out by hand and attached to the drawing. Not until four or five ECRs had occurred would someone update (or 're-draw') the drawing. This is only a snapshot of a few technical details that could be impacted. This small set of processes is what was intended to be replaced by automation. Given what was expected, what the developers actually decided to implement is a different story.

6.3.3 The Management-Solution Evolution

a) PDM Round 1

Either due to poor decision making or a major oversight, a poor management decision was made up front that started the effort down the wrong path. This would continue to persist as the project progressed. From Space's perspective, the decision to automate the configuration management of drawings was seen as a technical update, an information technology solution. It was not seen as addressing an engineering process that might need to be re-defined or adapted in parallel with determining the best software for the job. This proved to be a significant hindrance to the success of the transition. In addition, there appears to have been very little accountability throughout the process by knowledgeable people whose input would have been beneficial in shaping the course of action

The project was led out of Space's internal IT organization. A core team of three or so took on this exciting new project and set out to bring MED (and Space, they thought) into the digital world. Without much input, other than from the retiring supervisor of MED, they went out and benchmarked a few companies, reviewed trade journals, and talked with vendors about the latest solutions for drawing management. The IT team fell into two major traps. Firstly, they failed to establish a relationship with any of the system's users in Space. They failed to consider the current way things were done in terms of how the engineers worked. They only saw what the new potential capability was and perceived it as 'better'. Secondly, a very persuasive member of the team became sold on vendor software that had fundamental issues with actually delivering a functional product.

The IT team decided to use a COTS vendor solution. This decision was partially due to the recent advances in the tools, and partially because of the trend they saw in industry. Not only did the vendors promise the capability of configuration management for the CAD files, they also had an amazing ability to automate the engineering design workflow. This capability was accompanied by promises of decreased cycle time, less rework, and overall productivity improvements in the engineering design process. Any good IT department wants the best tool for their organization. This team was no less determined.

What the team ended up with was a great new IT tool that would revolutionize the way Space did design engineering. However, instead of only replacing the drawing filing cabinet, they tried to deliver a host of other capabilities as well. Without having asked the engineers about their processes, the IT team had a cookie-cutter vendor solution that did not fit into the Space organization. With the tool's implementation, they had allowed the software solution to drive process change that the users were not ready for and did not want.

Due to in the inherent flaws in the solution and the resilient culture of Space, the PDM deployment did not go as planned. The users essentially refused to adopt the system. Although some portions of it were implemented and used, the solution as it was architected did not survive. This experience left the users wary of the system and its advocates. The PDM initiative lost a lot of steam and had a hard time over the next six years pulling it back together. Meanwhile, Space's need for a system that could deliver more capability was growing based on changing competitive and collaborative needs, whether the users or upper management realized it or not.

b) PDM Round 2

Over the next four years, several changes in management took place regarding the PDM group. As the project struggled to keep progressing during this time, what emerged was an essentially new team residing in Systems Engineering (SE) instead of being CAD-focused in IT. The CM organization was moved into SE, which was critical given that they would represent a large percentage of users for the PDM system. The project was renamed at Space and the process restarted. Requests for Information (RFIs) were distributed, a trade study based on real engineering requirements and user needs was performed, and a product was selected based on its open-architecture philosophy and ability to meet the needs of Space.

In 2000, site licenses were bought for the product and a pilot production phase was implemented to ready the software. As the project and its following grew, so did the team, including an IT staff that would do the internal development of the software, user interfaces, special reporting, etc. User group meetings were established to continually gather requirements from programs, as well as inform them of what was coming down the pipeline. The changes in management and organization at the division level have definitely shown an impact, in Space's case, of how critical the placement of an IS solution within a company is. However, they continue to struggle due to lack of support and priority from senior management. As described by the supervisor for the PDM organization, "You can get management to bless it, but not enforce it." This has reflected on their effectiveness within the organization.

6.3.4 Barriers to the PDM Solution

The team of engineering and IT continues to push forward, working with and providing a strong support team for users as more programs come on board the system. The roll-out has been on a program by program basis due to Space's culture and it limiting the diffusion of the system. Additionally, the ability to mature the solution has been slowed by the lack of resources provided by the organization, as well as the technical challenges that have been faced.

a) Cultural Challenges

The unique culture at Space has made it very difficult to implement a common system across the company. Much of the work that takes place is research oriented and at the cutting edge. The workforce is composed of a high percentage of personnel who hold advanced degrees. Programs are generally given their requirements and then allowed to go do what they do best. The environment is very project-driven and there is not a strong culture of centralized, enterprise-wide management. Naturally then, use of the PDM system is not being forced across the company as it would be in more traditional aerospace companies.

The CM assigned to each program is the largest user group of the PDM. This is partially based on the processes, and partially because so many refuse to use the system. Potential users avoid it all costs, making it easier in the short-term for the CM personnel to do it themselves. According to the Configuration Management Supervisor, "Resistance is really in upper project management. They won't log in to the system so you can't get them to do an electronic sign-off." The Quality Assurance (QA) organization uses the PDM for its processes as well, and has similar difficulty getting the chief engineers' signatures. The system requires a user to sign in to the system to know what should or needs to be done. This culture has forced the organization to support a parallel paper process, obtaining needed signatures by hand and then scanning them in to the system. In addition, it has caused the actual users (CM and QA) to track the needed signatures by hand or by using Excel spreadsheets.

As with the rest of the aerospace industry, a large portion of Space's workforce was trained in a culture of no computers. Over time, as technology became a part of the engineering culture, a surprising number of employees resisted using the new technologies, including basics such as computer-aided drafting and e-mail. To this day, there are senior designers that, because of their knowledge and experience, continue to work without ever logging onto a computer. As told by one employee, "You'd have to pay for [the junior designer's] learning curve. A senior designer can draw it in one day versus five, so it's cheaper to pay two people." The junior designer would then recreate the paper design with the appropriate modeling software.

There is some user mistrust of the PDM at Space. This can be partially attributed to the initial implementation that did not meet expectations. The other, more general reason is that using a PDM requires an engineer to make his or her data available to anyone else with access to the system. They no longer control who see or handles the data. Space's PDM system is constructed fairly rigidly, according to some of the heavy users that are commonly called on by others when a problem arises. The rigidity is to limit errors when entering data into the system, but it also can corner them in the system and then they are not sure what to do.

Although Space has standard processes at a high level, it has implemented a waiver system that allows programs to bypass these standard processes fairly easily. This applies to information systems as well. Over the years, programs have been allowed to develop their own information systems that suited their particular needs. Although the data management effort has now become more centralized, the culture continues to be dispersed because of the slackness allowed in the organization. Space's documentation states that "[Every program is] required to use [the company PDM] or an equivalent [system for data management]." Programs have a difficult time seeing the value of a centralized system, which has made it difficult to bring them under a single system with a single set of processes. This has put more onuses on the PDM team to 'sell' the system to programs, which is largely how it is being done.

As another example of the culture, because of the need for all programs to be ITAR compliant, a separate organization within Space has provided money to programs to update their individual IT systems, or invest in new ones. Space's site-wide PDM is already ITAR compliant and they are willing to work with every program. The money being provided to the programs is more than it would cost to make them "PDM-compliant", undermining the centralized efforts and wasting money that could be used otherwise.

b) Technical Challenges

As with most IT implementations, Space's PDM development has faced several technical challenges. The products that Space delivers and manages cover a wide engineering spectrum. Its product lifetimes range from a few years (not making it to production before being cancelled) to 40, where key parts continue to need maintenance and tracking. This spectrum means that Space generally has more variability in its product output and requirement needs. It not only has to meet ITAR requirements and industry standards, but customer requirements as well. Space does full-production as well as a high volume of prototyping.

This unique range of product needs meant that Space had some requirements of its PDM system that had not yet been addressed by software vendors. Additionally, the different program legacy information systems and divergent processes meant that legacy data and processes needed to be understood and compromised on to best serve the programs that wanted to use PDM, without sacrificing too much needed standardization. One of the PDM team's toughest struggles has been finding the right balance of customization and OTB software.

A key issue being faced by Space is that the current commercial off-the-shelf (COTS) PDM product has some shortcomings in meeting the way it does business. One designer commented during an interview that the system was made for how someone designs an automobile – not aerospace products. "Automotive has a stable design with many configurations. Space gets a job, creates a team, starts from scratch, finishes, and [the design] isn't modified after that. We need something that allows us to backtrack and take another direction; but we still have one destination." Out of the number of comments that get fed back to the PDM vendor regarding the system, the PDM Operations Lead estimated that 25% of them could be implemented directly into a near-future software release. That leaves 75% of them that are Space-specific, in order for the system to meet their needs.

c) Organization Challenges

Similar to the cultural barriers for the PDM system, the organization has provided multiple challenges. How the organization values diffusion of Space's PDM system site-wide is reflected in the budget allotted to its development each year, as well as how enforced, it is by management. Compared to the industry's investment over the last 10 years, Space's pales in comparison, especially given the unique needs to meet the organization where it is at. Along with other high-level IT systems, PDM seems to be treated more like a 'nice to have' than a necessity by management. This lack of priority at an organizational level has, in turn, made it difficult for the PDM team to exert any authority when working with the programs and preparing them to use the system.

The IT initiatives taking place on site are not necessarily organized optimally. There is a simultaneous ERP implementation taking place with the PDM. The two systems will have some level of integration so obviously there is needed communication between the two developments. This has been recognized and is occurring. There are other tools being bought and implemented independently, however, that arguably should be subservient to those developing PDM. There also are legacy systems within Space that need to be modified or abandoned if PDM is to serve as the primary owner of product data. The authority for these systems is outside of the PDM team's management, which has led to internal battles when there is no authoritative voice. Organizationally, it has made the PDM development more difficult because of the decentralization of projects that should be more integrated.

Finally, because the driver for PDM at Space was to manage product data electronically, the organization has had difficulty in seeing the tool's full potential. Their short and sparse production runs mean that there is little pull from the manufacturing side for tightening up the flow of data. There is a similar conundrum with product support, considering that very few of Space's products require or have an expectation of maintenance compared to what would normally be perceived in aerospace. The only 'pull' for use of the PDM system has been from the CM and QA employees, for use of the electronic sign-off capability.

6.3.5 Space's Enablers to Its PDM Solution

Given the challenges that have been discussed, there has been progress made in Space's PDM system, and information systems in general. Although the culture and organization have made many paths difficult, the freedom given to projects at Space and their unique position in the industry has helped the company. Its projects have met with success for several reasons.

The current approach being taken by the PDM team and their management is an engineering-centric approach. Although most employees on the PDM team have computer science backgrounds and experience, they are relatively young to the company and open to its needs. Notably, the team is being managed by an engineer who sees the internal IT organization as a service to the engineering community. Much importance has been placed on the projects' needs for their engineering processes and data. The team continues to learn about and work with programs, both transitioning new programs on to PDM well as integrating new needs or desires by those already using it. User group meetings occur on a regular basis, both in general and with for specific users, programs or needs. The CM and QA organizations (representing the largest number of users) have been working with them very closely.

The vendor of Space's PDM tool continues to develop modules for additional capabilities that are not part of the PDM core, while Space also invests in and develops additional software to meet program-specific needs. A collaboration tool, for example, has been highly desired by several programs to enable more advanced communication with certain partners or their customers. Being an add-on to the PDM, the team has been able to market their system to more programs given these additional capabilities. The programs are required to buy into the whole system in order to have the added functionality. This has added to the PDM's diffusion, especially as program's tout their new capability to other programs.

Another factor that has enabled Space's solution is its relationship with its software vendor. It is well-established, due to Space's use of legacy products in the past. Space is typically an early taker of product releases, which makes the vendor happy and gives Space an opportunity to give early feedback on the latest software. This has given Space moderate influence on the tool's development and general improvements, based on its needs.

6.3.6 The Current Solution

Space's PDM has been piloted on a number of major programs over the last few years, as other programs continued to use the legacy PDM. It has slowly added capability over the past few years in phases. This past year, Space started upgrading programs to the new PDM by introducing them to the new front end and user interface (UI). In the next two years, over half of the programs at Space will use the system. Space's target is to have 80% of programs using the system within a few years.

Currently, the biggest users of the new PDM system are the CM and QA organizations. Other expected users include some designers, chief engineers that integrate with the manufacturing processes, and any customers or otherwise collaborative partners. Use by the designers and chief engineers has been difficult because the CM and QA organizations have the ability to pick up their slack. As that has been tolerated, it has been difficult to enforce a policy otherwise.

All programs are still accessing records in the old database, as Space prepares to migrate another set of documentation from the old database to the new. Over 100,000 documents are scheduled to move in the next phase. The current system supports electronic sign-offs and drawing releases, Space's waiver system, and inspection reports for the QA department. However, a parallel paper process for all of the functionality continues to be supported due to non-users of the system. In addition, Space has integrated modules, such as the collaboration tool and a scheduling tool that integrate directly with the PDM. It plans to turn on small pieces of capability every couple of months to minimize user impact, and therefore resistance.

Along with the OTB functionality that has been tailored for Space's needs, it has added many internally required capabilities. These have been to accommodate a combination of Space's business practices (such as the waiver system), as well as program-specific needs such as uniquely desired reporting capabilities.

Quality assurances' processes are included in the workflow, but there is limited connection with the manufacturing side. Space's manufacturing system is in the process of being overhauled, along with the ERP implementation, so there are many future expectations of system integration based on the new initiatives. The goal is to loosely integrate the PDM and ERP, and eliminate the legacy manufacturing system.

The user interface of the PDM probably has the highest percentage of time spent on any individual part or concept. The PDM team has worked very hard to minimize user impact by standardizing the user interface (UI) between the legacy system and the new. Most programs using the legacy have already converted over to the new UI, so that when they are switched from one system to the other, the change will be almost unnoticeable. According to some of the users, the new system is not necessarily faster because the data is organized differently. In addition, one designer commented that, "Overall, it takes a little more work. [But because of how the system is set up], it is easier to start in PDM," as supposed to starting a design outside of the PDM and moving it in later. It is recognized by the designers interviewed that the value of the system comes from enabling the enterprise as a whole, to store, locate, and reuse the data being created.

6.3.7 The Future of Space

Over the last decade, Space's environment has become more competitive. This has served as an impetus to standardize its processes, as well as upgrade its information systems and how they collaborate within and without the company. This, combined with its need to share data with partners, as a supplier, or as a prime contractor, has greatly increased Space's need for collaboration capability.

PDM has the potential to be very valuable to Space, especially as its role and needs change over time. With the company's increasing need to be more competitive, more collaborative, and meet a variety of requirements, there has been an impetus to update and standardize processes as well as update its IT infrastructure. PDM has enabled the organization to adapt more quickly to these changes. It also has the benefit of allowing the programs to 'outsource' their data management needs, eliminating the need to acquire a system on their own and maintain it. Finally, employees at Space have the option to move around to different programs, so there is value in having every user trained on standard IT systems, as supposed to program-specific systems.

As the PDM brings value like this to Space, certain areas of management, such as the CM organization, have begun to endorse the system. Over time, this will hopefully provide more resources and credibility to the team, enabling them to provide a system site-wide. At that point, Space will reap the benefits of having a single, integrated system across a piece of the lifecycle (namely design). As the evolution of Space's needs pervades the lifecycle, PDM will be there to provide support throughout.

6.3.8 Space Case Study Summary

Space's culture has remained fairly static over its history. It quickly established its place in the industry as a strong research and development center, producing small quantities of specialized products. A high percentage of Space's employee base has advanced degrees which culminate a very academic, self-driven environment. This has resulted in a fairly Its business needs also differ from others in the aerospace industry, enough so that having a robust DM capability has not been seen as high a priority as it is for Aero.

Space's initial PDM efforts were driven by the need to replace the retiring director of its DM group, framing its 'burning platform'. The decision was made to automate configuration management of drawings. The assignment continued to reside in the IT organization, with little attention paid to it by upper management. The initial implementation consisted of the IT team selecting a PDM solution that could not only manage drawings, but also automate many additional processes. It launched the solution without involving any of the users or entertaining their input. Given Space's culture, the users essentially boycotted the system.

Over a period of six years, Space's PDM efforts struggled due to management changes, reorganizations, and an undefined internal IT mandate. Five years ago, Space declared that IT was not a core competency, its IT/PDM management stabilized, and a new, defined PDM effort emerged. Since then, it has successfully piloted its new system, involved the affected programs, and begun rolling out capability. As Space's environment grows to be more competitive and collaborative, its PDM capabilities have helped meet those needs.

Space continues to struggle, however, with its culture. Although a well-equipped team is in place and it is making smart decisions based on the company's needs and efforts, Space's transformation efforts as an enterprise will continue to be inhibited as long as the culture is given free reign over its programs' IT choices and management does not provide stronger budgetary and authoritative support for the effort.

6.4 *Comparison and Summary*

Two very different companies have been presented with varying contextual factors and success. Aero's PDM efforts have been well understood and supported, while those at Aero have not been given the same emphasis making it more difficult to enforce change in the organization. Although to different extents, both companies are considering more of the lifecycle than just product development data, but both still lack full integration even across engineering and manufacturing.

The case studies illustrate factors that can severely hinder implementation efforts as well as how difficult such changes can be regardless of the environment. Both companies underwent major learning curves based on their efforts and continue to improve based on their experience. Below is a table providing a snapshot comparison of the two companies and their PDM implementation efforts at the time data was collected.

Context	Aero	Space
Burning Platform	Save the Business	Save the Knowledge
Number of Programs	Less than 5; large programs	Greater than 200; 5% large, 35% medium
PDM Budget	Long-term strategy; Fully funded budget upfront	Short-term strategy; severely phased budget
Management Turnover	Very limited	Very often
Company Culture	Strong relative to industry	Strong relative to industry; more unique
Multi-CAD	Yes, internally and externally	Y, externally
Efforts		
Multi-site Effort	Yes	No
Data Model	Standard across programs	Standard across programs
Implementation Team Make-up	Engineering Driven; mixed	IT Driven; mixed
Implementation Approach	Phased by program	Phased by capability and program
PDM Solution	Nominal customizations; Standard across programs	Heavy customization of user interface; less standard across programs
Current Diffusion of PDM Solution	Complete implementation across the organization; being migrated to sister organization	Limited use within programs; not implemented to all programs

Figure 26: A comparison of company and PDM implementation characteristics of the two case study companies.

6.4.1 The Initial Tool Selection Process

Regarding the first proposed question regarding the process of how PDM came to be the solution of choice, some of Aero and Space's decisions were similarly made but they went through unique iterations. As represented by the second diagram in Appendix D, Aero's identified need was the inability to manage its products' lifecycle costs. The power of decision making was given to internal experts in the lean engineering organization which was fully supported by upper management. The implementation was driven from there as well. A trade study was performed and the desired PDM vendor was easily selected.

Space's process, as also illustrated in Appendix D, also started with identifying the need for PDM. Its need, however, was much more constrained, only automating control of released drawings. The solution was driven from the internal IT organization with very limited budget support and authority. After a problematic first attempt at implementing the system, Space re-iterated which included conducting a trade study that led to a similarly easy decision when choosing their desired PDM vendor.

6.4.2 Evolution of the Technology Versus the Organization

Questions were asked to both managers and users during the interviews to address this question. There were mixed reactions regarding how user's jobs were changing based on use of the PDM technology. Many said that they continued to use old methods of getting questions answered or looking for data, even though the PDM could be used for the same purpose. The argument was that picking up the phone and calling someone who could answer a question immediately was easier than trying to search for an answer using the PDM which was still unfamiliar. Communication patterns, superficially, seemed unchanged.

Similarly, management in both cases had new ability to monitor product development cycles and the location of documents, but did not necessarily take advantage of the ability yet. The only documented changes identified during the research were in the processes changed due to the PDM implementation. These were not studied extensively.

From a technology evolution perspective, based on all of the research data, many of the companies interviewed are actively involved in influential groups that try and steer the development being done by vendors based on what their business and process needs are. Customizations and changes made to the PDM technology by companies is often fed back to the vendors as well, which are often designed into subsequent COTS releases. The Aerospace and Defense template used by UGS's Teamcenter product was developed in a similar way, as well as the inclusion of ITAR-compliant workflows (CIMdata 2004).

6.4.3 Lessons Learned From the Case Study Experience

The following recommendations are enumerated based on the experiences of Aero and Space:

- One size does not fit all: The two cases used contrasting IT implementation approaches. Their strategies were a function of resource availability, management commitment and system understanding. The approach adopted must reflect limitations imposed by the organization, technology and culture.
- Authority to transform the enterprise: The team given responsibility for designing and implementing the system must be given authority and the requisite budget to drive change.
- Gaining user commitment: Not communicating the criticality of transitioning to the new system is a common stumbling block in gaining user commitment. This requires user involvement in the process redesign as well as training of end users in the process changes and in using the tool itself.
- Managing process evolution: A successful execution requires management of process changes before, during and after system implementation.

Chapter 7 . Conclusions

7.1 *Introduction*

This research was based on a sample of companies currently involved in PDM efforts. The conclusions regarding data management are therefore representative of companies with a PDM or similar tool in place. The conclusions drawn regarding effective implementation practice and the value a PDM can offer are applicable to the more general aerospace community.

As observed in the research, there are many companies that have taken management of engineering data very seriously, and have been successful at improving that capability. Many have struggled, however, to view the creation and management of engineering data from a lifecycle perspective and integrate the engineering data with other data in the value stream. Delivering value at the enterprise level requires integrating data seamlessly across the lifecycle. Managing engineering data very well and business data very well but not connecting the two results in a sub-optimal process, limiting the overall value delivered.

As reported in the results, companies had expectations characterized by high-level requirements when they chose to implement a PDM. Some expectations were in the form of fixing something broken, while others were more value-driven such as visibility to the process and traceability throughout the lifecycle of a product. There are two ways in which a PDM's value based on the information and process flows is delivered to the enterprise: horizontally across the lifecycle, and vertically from the customer through the supply chain. What we have seen is that often this holistic impact of a PDM, horizontally and vertically, is not considered when the PDM is implemented, so the value is lost. We also observed other unfortunate practices such as a disconnect between management and the implementation efforts across all of the companies.

In the following conclusions, there are observations that raise concerns regarding the process definition taking place when implementing PDM and similar technology. Also, there are benefits derived from a PDM implementation that facilitate an enterprise as it continues toward lean operation. Although these lean implications are mentioned throughout this work, they are specifically enumerated as part of the final analysis.

The following diagnosis attempts to provide clear examples and data from the research to illustrate the above points. There is strategic importance in implementing a PDM that is being overlooked due to the oversight in how the PDM fits within and enables the enterprise through. Tangible and intangible benefits are being undercut due to poor implementation results. Although hard to quantify, there is definite value to be gained through having product data managed effectively and efficiently, enabling a large portion, if not all, of the lifecycle data stream for any product.

7.2 *Horizontal Implications – Spanning the Lifecycle*

The aerospace industry's efforts regarding product data management are focused on managing engineering design data and not integrating the data with the lifecycle.

As seen in Figure 16, many types of data created downstream of the EBOM and MBOM are managed by stand-alone homegrown and legacy tools, or hardly managed at all. Based on the past and future comparison of data management in Figure 17 and Figure 18, there does not appear to be a significant change forthcoming in this effort. The first of the four PDM maturity questions, reported in section 5.10.1, shows that eight of the nine sites had a score of 3 or less implying that they still support many resident legacy data systems and have limited integration of product data with partners and suppliers.

Only one out of eight sites currently had their PDM tightly integrated with another business system, their MRP. Four additional sites had loose coupling established between their PDM and either their ERP or MRP system. Two more had plans to tightly integrate their PDM and ERP systems, a growing trend, but had not been able to do so as of yet. Any other tool integrations were less sophisticated, being handled through flat file or manual transfers.

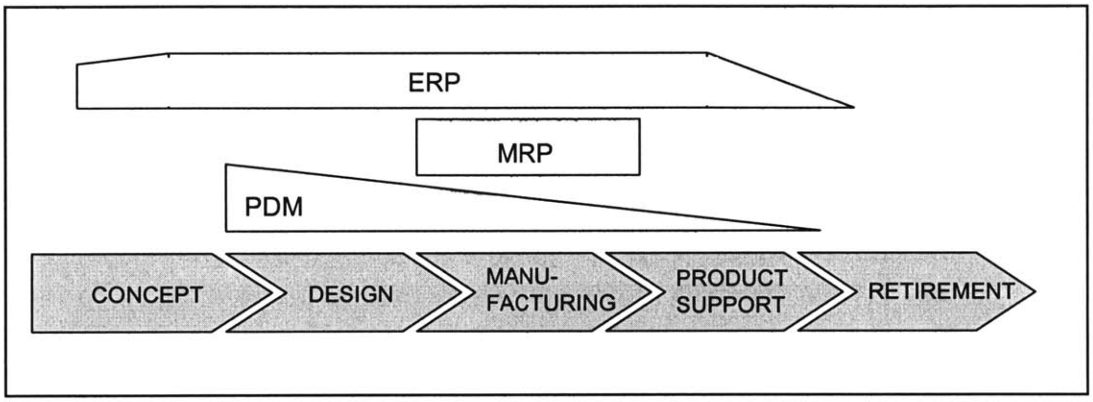

Figure 27: A conceptual map of where three enterprise information systems overlap in the lifecycle.

As currently implemented, PDM is only managing a portion of lifecycle data and is therefore one part of a bigger IT infrastructure. PDM, therefore, should not be treated as a stand-alone tool so the effort of designing and implementing it cannot be independent from the rest of the infrastructure (DP 2002).

Although many of those interviewed in management were cognizant of the importance of lifecycle value and could discuss it, actual integration efforts of data across the lifecycle were not observed. In the interviews, there were a few examples where the PDM either was or was planned to be coupled to an ERP, but data shared with other systems were typically transferred manually. Three of the sites scored a 3 on the fourth maturity question regarding the amount of tool integration while the other five scored below 3. Interviewees often had difficulty providing information on whom or what managed certain data elements. An attempt to understand the level of integration between business systems at a given site proved difficult and it was observed that there was often very little integration.

Ultimately, the value at the enterprise level is degraded through the hand-offs that occur between information systems across the lifecycle, especially systems that still require manual transfer of the data or in sever, preventing a seamless flow of data.

7.3 *Vertical Implications – Customer, Prime, and Supplier Integration*

A large amount of knowledge is lost due to weak integration as data flow from prime companies to the supply chain and beyond.

The data being created to design, build, and support today's aerospace products have much more complexity than in the past. Although there are means available to manage this complexity, there is a lack of capability within the supply chain data management systems such that knowledge is being lost as product data are transformed from robust prime data management systems to lower-level supplier systems and capabilities. The data being shared are in most cases sufficient for the minimum work a supplier is required to do, but may limit knowledge transfer and therefore other opportunities. The difference between prime and supplier capability is seen in section 5.10.2 where maturity responses are compared (Shaw et al. 2004).

The data indicate that prime companies have a higher overall maturity, and that they have spent more money on PDM implementations (Section 5.5.2). The implication of this is that as prime contractors increasingly shift more of the design detail and manufacturing responsibilities to first tier suppliers, suppliers will need to have more robust data management capabilities than previously necessary to successfully manage these responsibilities. The data show an emerging need to assess the needed investment in supplier data management capabilities.

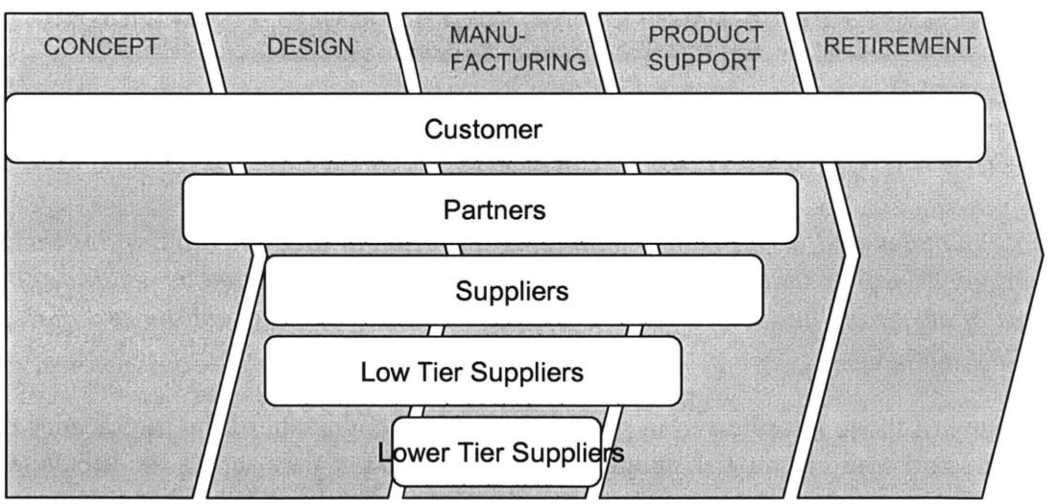

Figure 28: A conceptual map of how stakeholders integrate with the lifecycle.

The lack of customer, prime, and supplier integration limits the ability to provide a collaborative environment.

Customer requirements and other front-end data are typically collected and stored in native tools or in other non-standard forms. This makes them difficult to link directly to the products being designed to meet those requirements, thereby reducing the traceability. The data that are then transferred to a supplier typically consist of a limited subset of the original data, due to the supplier not having tools with the same sophistication. This limits the supplier's ability to make value-added suggestions such as a design modification or to provide input to a problem being faced. The inability to deliver that information richness both downstream to the supplier and upstream to the prime reduces the supplier's role in innovation.

Many government customers still require paper documents to be delivered due to lack of IT systems to handle the information. Paper also persists due to the amount of legacy information in the prime companies, and due to suppliers that do not have digital data capabilities. Collaboration with suppliers, especially at the third tier level and below, was still heavily done on paper, over the phone, and through limited web applications. Only half of the companies interviewed had a standard process by which supplier product data were handled. In many cases, the data received from suppliers are not being entered in the PDM or another configuration management tool. As indicated by Carlile's work, not utilizing the richness of data available for collaborative activities can hurt a team's performance.

7.4 *What Makes a PDM Implementation So Hard?*

7.4.1 The Data and Technology

Based on the observations discussed, it should be clear that implementing a PDM correctly is not an easy undertaking. There are many contributing factors including the amount of legacy data residing in different places, the integration efforts between ever-changing business solutions, and the business solutions themselves. The definitions of technologies and what they offer changes constantly, while in the background engineers and managers are already trying to manage changes to their native tools. Figure 16 provides a snapshot of how differently programs within just nine company sites are managing their data. The amount of data, number of stakeholders, and number of systems to standardize across makes the process difficult.

7.4.2 Confronting the Culture

The cultural challenge faced in these PDM implementations is weaved in throughout this entire thesis. Starting from the process changes that occur up front, through the training, acceptance, and learning after deployment, the user community of the organization is the customer. If they are unhappy with the final solution because they cannot locate data, a screen takes six minutes to load when it used to take 30 seconds, or they do not understand how to enter data in the new system, they will naturally do whatever possible to avoid using the system. According to the interviews with those involved in implementation efforts and user support, users will even avoid using the system based on unfamiliarity and a desire to not "change", regardless of whether the system works or not.

A company's culture has power in these situations when management does not get involved because the implementation team is the minority. Understanding and expecting cultural resistance with any major changes is the first step in building a PDM development and deployment plan that is robust to it. It is then management's role to provide the authority and support to the implementation team. If management allows pushback for the sake of pushback, the PDM deployment will struggle more than it should and the business will suffer in the end.

Getting user buy-in during the development path is essential for addressing the cultural resistance. The organizations that discounted cultural resistance had a more difficult implementation period than those that expected and planned for it, and some have yet to complete their implementation because of it. Opportunities to get users invested in the changes, such as during the process re-definition and training, are often overlooked.

7.4.3 Management Practices That Lead to Failures

a) Understating Change

Although it may seem an overstatement, observations from the research support that management typically does not appreciate the difficulty of implementing a PDM-type solution. PDM represents a large infrastructural change that impacts the enterprise from all directions: the organizational processes, the culture, and the technology infrastructure. The managerial and budgetary support required to successfully follow through on thorough, effective implementations was often underestimated in the companies studied[2]. The Space and Aero case studies illustrate both sides powerfully in Chapter 6 However, there are three predominant effects in PDM implementations observed during this research: conflicting business or IT solutions, the level of involvement of users and managers, and internal support policies.

b) Conflicting Solutions

Deming's constancy of purpose and observations from aerospace community IT research (Shaw et al. 2004) rang true where US management tends to drop an active project or focus prematurely on a new one without fully implementing an earlier initiative. Seven of the nine sites were struggling with corporate initiatives that were in conflict with the changes the site had committed to implement at a local level. In some cases the corporate initiative made it a challenge to secure funds for the local initiative while other corporate initiatives were directly contrary in terms of the specific PDM chosen for corporate-wide use. The implication from the research is that the decisions being made at the corporate level are not comprehensively considering all of the affected stakeholders and their needs. This could imply that decision makers at a corporate level and those at a site level are able to communicate effectively or take into consideration the impact that given decisions are having elsewhere in the organization. It is also possible that vendors are doing a poor job in conveying what such an enterprise implementation of IT requires.

c) Involvement Level

As reported in section 5.7.3, only five sites were satisfied with their management support. Fewer than half of the programs interviewed were satisfied. There were typically three levels of management involved: the corporate level, the site level, and middle management at the site. Middle management was typically in charge of seeing the implementation through. In cases where sufficient site management support was not present, the implementation would suffer either due to resource restrictions, or setbacks from cultural push-back. Without realizing their responsibility to see their local efforts through, the site management would not defend their

[2] I make a Halo video game reference at this point, partly because this is an MIT thesis, partly because someone at Krazy Haus will appreciate it, and partly because it is illustrative. Watching a friend drive a tank through a war zone in Halo 2, I asked what the strategy was. He said "You have to keep moving. Shoot at things but whatever you do, don't stop or you will never make it out alive." For managers who were successful in leading change in their organization (with PDM), this is essentially what they were prepared to do and delivered.

current efforts against new corporate initiatives. This created instability in completing the implementation. Such management practices have led to numerous examples of unfinished transitions, continued paper processes where the new system was not successfully enforced, and PDM efforts being put on hold indefinitely.

Poor management predestines any major enterprise-level IT implementation to failure. The following are management guidelines and considerations based on good practices and experience from the companies interviewed:

- Management that is unclear or dynamic in their IT vision and strategy create an unstable environment for the transformation required for most PDM implementations.
- Delegation of authority and accountability to the implementation team are necessary but not sufficient actions for a successful PDM implementation.
- Strong, unwavering upper management support is apparent in the most successful examples, leading to strong budget support and enforcement of the user community.
- Communicating the impending changes clearly and often will prepare the user community and provide opportunity for feedback, reducing user resistance.
- A recurring recommendation from the interviews was to "Run it like a program" meaning treat the PDM implementation the same way as any other program with a set of requirements and product deliverable, on a defined schedule and budget.

7.4.4 Policy Effects

Internal to a given company, there are many examples of diverse agendas regarding corporate policies and mandates verses what the site is trying to accomplish. Before an all-encompassing requirement for something such as a business information system is mandated, corporate should take great care in establishing a well-informed, comprehensive understanding of their business unit initiatives and needs. This includes being prepared to assist in making appropriate transitions from one to another, or providing opportunities for a site to complete its current initiative before complying with a new directive.

7.5 *Large IT Implementation Guidelines*

Several choices are made when developing and implementing a PDM such as how to conduct training, or if and how the technology will be integrated with other tools. The organization and its needs should always be considered when making these decisions, but this context will be the *driver* for a sub-set of those implementation decisions. Based on the research, a collection of implementation guidelines has been categorized as those that are context driven and those that are not. A large component of the implementation approach guidelines was derived from the Phase Two case study experience.

7.5.1 Context Dependent Guidelines

a) Implementation Approach

Companies are using a combination of both phased and big bang approaches based on the following contextual factors: management environment, number and size of programs or projects, size of user community, extent of integration with other business systems, extent of integration with suppliers, partners, and customers, IT implementation experience (Bharadwaj 1999), culture, and budget and schedule constraints.

The case studies clearly demonstrated two very different contexts and the conclusion is that the approach was driven primarily by the management and budget support provided in each. With extensive budget support and strong management authority, Aero was able to do a phased approach by program, but roll out capability to each individual program all at once. Space, due to limited budget support and management authority, was unable to achieve its team's desired capability in the desired time and has been forced to use a program- and capability-phased approach.

Generally speaking, for sites with very distinct large programs that have much legacy data, it is sometimes more manageable to go program by program. For those with more homogeneous products, such as an electronics supplier, the user community was brought on to the system within its functional roles.

Table 6 illustrates the factors that should be taken into consideration when determining the best approach for an implementation. There are pros and cons to each, and the system as a whole must be addressed in order to fit the right "solution" to the implementation "problem".

Table 6: A compilation of the suggested implementation approach based on given program and/or site characteristics as observed through company experience and performance.

		by Functionality		by Program	
		Phase	Big Bang	Phase	Big Bang
Product homogeneity	high				x
	low			x	
Legacy product data	high volume	x		x	
	low volume				x
Legacy IT	high	x		x	
	low				x
Maturity of the SW	high		x		x
	low	x		x	
Budget support	strong	x			x
	weak	x		x	
Management	will enforce	x			x
	won't enforce	x		x	
Overall Implementation Complexity	high	x		x	
	low		x		x

There are benefits and costs associated with both the phased and big bang approaches. The pros for the phased approach (and consequently, the cons for a "big bang" approach) are:

- Uses small manageable steps, minimizing the chance of a large, costly mistake
- Provides the ability to realize gains quickly and show process improvements are real - builds management support and user buy-in
- Provides feedback in a more timely basis to make improvements as you go
- Users are more easily trained due to more focused sessions (instead of everyone all at once)

- Allows you to coordinate with production schedules more robustly
- Appears to be less chaotic from a "disrupting the business" perspective
- Allows concurrent development of a second system, such as an ERP to take place

The downsides to following a phased approach, which serve as the positive reasons to use a "big bang" approach are the following:

- Can cause weariness in users and organization due to large implementation period
- Difficult to keep speed and momentum over a long period of time
- New upgrades or changes take place before the solution as a whole has time to be implemented and accepted
- User resistance has to be dealt with over and over again, instead of all at once
- Higher risk that a competing initiative will stop or hinder progress mid-course

b) Planning and Scheduling

Only one out of the nine implementations studied delivered on schedule. The evidence shows that in every implementation unexpected events occurred such as software release changes, corporate or company policy and initiative changes, and scheduled implementation activities that took longer than planned. Data quality and migration were the area most cited where additional time and money should have been expended. Interviewees that had experience with previous implementations were resigned to the fact that inevitable course changes would occur. An ability to plan flexibility into the schedule would be beneficial in allowing the team to address problems as they come up, having smaller impacts on the overall schedule.

7.5.2 Context Independent Practices

a) Implementation Leadership

Four of the companies studied currently manage their implementation teams through the IT organization, and five of them manage theirs from the engineering organization. In either case, the team composition is a mixture of IT and engineering.

It is clear that over time the organizations learned the importance of having engineering heavily involved in the development and deployment of the PDM system. Not including engineering in the development, as shown in the Space case study, leads to the development of a poorly suited solution for the enterprise.

b) The Role of Engineering in IT

IT personnel are commonly out of their knowledge domain when addressing engineering and how the engineers plan to use the tools. The same argument is made for gathering requirements. Someone who has not been an engineer will have a harder time communicating the gap between what the system users are accustomed to doing and what the new PDM is capable of doing (or how it does it). In order to get user buy-in to the tool and effectively communicate changes to the user community, engineering personnel must be involved in that process.

c) Stakeholder Involvement

During each site process interview, the interviewee was asked whether stakeholder identification and related value identification for those stakeholders was performed. In most cases, a stakeholder assessment was not done. This made it difficult for the sites to show the value delivered on a stakeholder basis after the implementation beyond the everyday users that have direct contact with the PDM (Melarkode et al. 2004).

Regarding stakeholder participation and buy-in, performing well-planned and well-supported process reviews seems to be the prime opportunity to get input from the user community which secures buy-in of the new processes. Sites that did a good job at this had an easier time with converting the user community to the new processes and system.

d) Data Migration

Eight of the nine implementations studied required a certain amount of legacy data to be prepared for use within the PDM. This included both paper and electronic records. One site was migrating up to 12 million records over the course of their site transformation. Every site that migrated data also underestimated the time it would take and the effort necessary to do it correctly. This was the most common schedule set-back observed. Buffering the schedule for this implementation activity seems advisable given the collective experience of the sites.

e) Training

Training, due to its position in the schedule, tends to be overlooked or underdeveloped, which contributes to user resistance. From the interviews, even well-planned and well-attended training sessions did not guarantee a knowledgeable user community once the new system was in place. The most successful training activities among the companies surveyed took place within four to six weeks before the roll-out and included training focused on specific user groups and their needs. A common recommendation from the companies was to make the training more hands-on and life-like as opposed to passive.

Similar to the experience reported in section e) above, engineering experts should be involved in the development of training materials in order to bestow credibility and eliminate many common assumptions or mistakes.

f) User Support

Having an organized, well-staffed user support team during and after implementation can greatly enhance the company's ability to make important changes to the system and reduce user resistance during the post-development phase. Anecdotal evidence from the interviews suggests that three months is the typical time for user feedback before activity drops off. The times when this did not occur, it was due to notably unsuccessful system functionality which caused continued user unrest.

7.6 *Re-emphasizing the Importance of Process Definition*

Processes and how well they are defined and followed is something often talked about and debated over. It has been clear through the research that all of the companies gave processes some consideration during their PDM implementation activities. What was also observed, however, is that the emphasis and breadth of process development during the system development and implementation is mixed with varied results. If a PDM's potential impact in the enterprise is being exploited, this should be apparent by examining the breadth of processes that are being examined based on the PDM implementation. Again, process networks both horizontally and vertically in the enterprise would convey that the PDM's full potential was being taken advantage of.

The robustness of the process efforts is of significant importance. Glen Parry's work from our UK LAI counterpart regarding ERP implementations showed that when process redefinition was not done properly or at all, the system implementation was worthless. Other authors have emphasized the value of focusing on process improvement a priori similarly. If the right processes are not in place to start with, then the processes being enabled will not deliver the efficiency or effectiveness possible to the enterprise.

Efficiency, regarding how quickly and correctly data moves for example, can be hindered if the processes being enabled through the automated workflow have many unnecessary steps or steps that over time have become out of place and misleading. An old process that is no longer valid may go unnoticed if an employee has been using a workaround to correct it manually. Unrealized, once this process is enabled through the PDM, time has been wasted in its implementation. Once it is realized that the process is invalid, more time and efforts are wasted in trying to establish what the current process being used is, whether it is the process desired to be used, and then re-implement it.

Effectiveness, which can include delivering the correct information or providing visibility into the system, is also lost when the processes are not reviewed to ensure that proper integrations are made with different organizations and systems. It is difficult to correctly understand which processes should and will be impacted by a PDM implementation without doing a value stream map or specific process identification.

There is an emphasis here in ensuring that process identification and redefinition is not done superficially. A real assessment of the cross-cutting processes throughout the lifecycle and supply chain does more than just provide opportunities for process improvements that will directly impact an enterprise's ability to deliver a better product. It also, in conjunction with deciding to implement a PDM, presents a rare opportunity to involve all of the affected stakeholders and get user buy-in of the changes being made and the infrastructure being implemented. Companies need to re-evaluate how they conduct their process review and change activities. Taking a lifecycle approach to fully review and enable core functional processes will allow the implemented system to enable the enterprise rather than a single function.

7.7 *Enabling Lean Principles*

Building on the benefits of implementing and using a PDM, each of the six principles of a lean enterprise is enabled in different ways. These are enumerated in Figure 29. Thorough preparation for a PDM implementation provides the opportunity to get rid of "waste". Examples include the elimination of unnecessary processes and redundant systems. Such a large infrastructure change also provides the opportunity to re-address stakeholder needs and desires, and make changes that ultimately deliver more value.

The Principles of a Lean Enterprise

Waste minimization
- Elimination of redundant data and systems
- Provides a single integrated interface for users

Responsiveness to change
- Ability to identify where the change can/should take place
- Single-point change as supposed to distributed systems and processes

Right thing at right place, right time, and in right quantity
- User ability, whether a designer or chief engineer, to locate the desired information when they desire it with the security of mind that the data integrity is intact

Effective relationships within the value stream
- Opportunity to address relationships and interfaces across functions as well as in the extended enterprise

Continuous improvement
- Enables visibility into the organizational processes
- Provides the ability to effectively locate process bottlenecks
- The technology provides new capabilities within the enterprise and the opportunity to make improvements

Quality from the beginning
- The data, from the time of creation, can be configuration controlled
- Reduces chance of mis-placed or obsolete data

Figure 29: Lean principles and how they are enabled through good lifecycle data management.

7.8 *The Value of PDM – How Do We Get There?*

7.8.1 The Business Case

The actual value of any major IT product before and even after implementation is highly contentious. Both the interview and case data, as well as literature, show that the actual implemented solution will have changed over time and will typically not deliver the complete capability that was initially intended. This results in an inability to meet the business case expectations, possibly establishing management resistance for future efforts. In many of the interviews, it was learned that the business case was either not accurate or not closed but the PDM implementation was approved irregardless because of the urgency of data management issues.

As PDM is promoted to enable more seamless information flow throughout the product lifecycle, benefits such as those experienced through digital data sharing with the supply network, and safety enhancement in product support will be experienced. The ability to recognize unquantifiable and intangible benefits of PDM, understand their value to the enterprise, and communicate them is the current weakness in the business case.

There were some frequently cited benefits of using the new PDM system. The benefits for the user were: the ability to find all engineering data together in a central repository, ensured data integrity, and greater accessibility to data. The most cited company benefits were: working in integrated systems with more effectiveness throughout the enterprise, including elimination of replicated data, configuration control with the elimination of physical vault, and ensured data integrity.

7.8.2 The Reality of Product Data Management

The promised value of PDM to the enterprise is not being realized. Unsuccessful implementations are commonly due to one of two categories. The first is lack of organizational readiness which manifests itself in several ways including lack of strong management support, resources including personnel and funds, incomplete process reviews and changes, and poor planning which affects any given implementation activity such as establishing user buy-in, training the users, or executing data migration (Melarkode 2004). These shortcomings were articulated as problems throughout the research.

The second is a shortsighted approach in how the PDM solution is designed and implemented. We see from the research that PDM's integration both horizontally across the lifecycle and vertically from the customer down through the supply chain is very limited. The ultimate goal of seamless information flow, providing the right data to the right person and place at the right time is gradually being lost through system hand-offs and data transformations.

There are considerations at the government level that need to address what policies can be reasonably implemented by the industry. These include legacy data maintenance requirements and the standardization of data formats and transfers that affect how different systems integrate and operate. These decisions impact the industry's ability to simultaneously meet its extended enterprise's and customer's needs.

PDM has been shown to provide the ability to manage ever-increasingly complex networks of product data and allow companies to remain competitive in such an environment. The Aero case study illustrated an ability to manage product costs through the BOM management provided the PDM while other articulated benefits include providing transparency and accountability to the process, and faster design cycles. All benefits will be lost or could be severely impeded, however, if the PDM implementation is a shortsighted effort either in its development of breadth and integration, or as supported by the company management.

PDM provides the industry an opportunity to challenge its organizational processes and structure when implementing a PDM or similar enterprise information technology. The aerospace industry needs to not waste the opportunity afforded by a PDM implementation and use lean principles to help identify enterprise changes that will lead to more effective processes, driving the networks and flow of people, processes, and data that enable the design, manufacturing, and support of critical commercial and military engineering feats.

7.9 *Future Work*

The companies addressed in this research all had a minimum level of capability and experience with PDM. The breadth of information presented here regarding data management capability in the aerospace industry and shortcomings in both implementation practices and enterprise mentalities provides a basis for several future research opportunities. The importance of successful data management and integration across changing interfaces and borders continues to become more important.

A comprehensive survey of what enterprise IT systems and level of integration resides in all stakeholders within the industry would further develop the understanding of how well companies are leveraging their enabling IT infrastructure. Some of this work has been done (Shaw) but is not currently comprehensive vertically through the stakeholders and horizontally across the lifecycle. Expanding this data set to automotive and European aerospace efforts and capabilities would also be useful. In doing so, a more comprehensive set of "success criteria" could be developed, further enhancing a maturity model for the aerospace industry. This could enable us to further the development of meaningful metrics for the industry.

There is a research opportunity in understanding the effectiveness of data management and knowledge-based collaboration technologies. Some previous work on collaboration has been done regarding the physical distance between co-workers and the methods they often use. How technologies such as PDM affect the effectiveness of relationships between co-workers, both internally and across the globe would provide information about the benefits of such systems. In conjunction with expanding the data set to European aerospace and automotive efforts, the comprehensive understanding of who has what capabilities provides a mechanism to then understand what the actual collaborative benefits currently attained by PDM , etc. are given the different capabilities at different levels in the value chain. It is not clear whether increased collaboration is a true benefit of a PDM or not. This research suggests that the value of PDM comes in other ways, but PDM may ultimately be an enabler in providing collaboration capabilities.

There were two high-impact decisions being made that were identified in the research and require more data to make robust recommendations. The first is regarding the implementation practices. The data was clear that experience caused a convergence of certain decisions but additional interviews at a larger diversity of organizations would strengthen the implementation guidelines. The second has to do with the decision every company involved in the research was faced with: whether to maintain legacy data in its original form, or pay the price to digitize and/or migrate it to the new data management system so that it would be easily accessible and available. The decision to upgrade legacy data is very expensive but in some cases programs felt it was necessary. Further research could help build the business case for such decisions and influence the way in which implemented policies at the government level enforce such decisions.

It is clear that converting all legacy data for every program is not feasible from a resource perspective.

Very little time was spent looking at current and developing data sharing standards, and their potential impacts. There are efforts being undertaken by organizations to develop platform cross-cutting technology that will enable standardization in data sharing and management. This is one method being exploited in the space where research could help determine what standardization is important and how it should be implemented through policy changes. The costs of enterprise IT systems are significant enough that enabling collaboration and integration across borders through standard interfaces and formats is becoming increasingly important for the industry.

Finally, there is a new research area focused on developing metrics to help diagnose the enterprise. An important focus of these metrics will be in determining how well an enterprise's data is being created, managed, and shared across the lifecycle at all levels. Providing a diagnostic and identifying the gaps in the IT infrastructure would help enterprises in their investment decisions.

As the costs of providing information technology to enable data management are high, so are the costs of doing it ineffectively. This research has laid the stepping stones for many other rich research opportunities that can further the industry's ability to prepare their organizations for better delivery and support of products that provide increasingly critical capabilities in our world.

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Appendix A: Phase One Data Management Maturity Worksheet

Scale Questionnaire: Extent of Deployment for PDM

Look at the following defined categories and rate your site or program based on the current level achieved (mark with a C) and the desired level (mark with a D) as defined in each box. Circle the number that applies. All descriptors must currently be attained in order to be valid. Feel free to make any clarifying comments to the side.

Definitions:

Function – a functional group such as design or manufacturing or marketing, etc.
Internal – within the boundary of a site or program; excludes other company sites
External – referring to other company sites, partners, the supply chain, etc.

1. Integration of product data across the product lifecycle

Scale:

1	2	3	4	5
Product data (PD) in several disparate locations; difficult to locate and retrieve data	PD residing in several legacy systems; major systems are interfaced with PDM	PD residing in primary legacy systems; legacy are integrated with PDM; PD interfacing with prime suppliers and tier 1 and 2 suppliers	Only one or two legacy systems per major function; integration with PDM; All prime and tier 1, 2 supplier PD is integrated	All PD stored in a single database (DB) including critical supplier data including international partners or supply chain

2. Extent of supplier/partner integration

Scale:

1	2	3	4	5
All PD is handed off; replicated/shared via paper	Most PD is stored electronically; domestic tier 1 suppliers have access to relevant PD via paper	All critical PD is electronic; some internal and tier 1 supplier electronic distribution	Prime can share all PD electronically throughout company and majority of the supply chain	Comprehensive supply chain has access to pull and create data rather than be handed the data only

3. Management of workflow electronically throughout the product lifecycle

Scale:

1	2	3	4	5
Processes are not standardized; not well documented; processes and workflow not managed by PDM	Standard processes with disciplined approach; no electronic workflow	Workflow electronically managed within functions e.g. engineering design and/or manufacturing, etc	Workflow managed across functional boundaries (design, manu., and product support) by PDM; some external workflow is managed	All processes are streamlined and managed through the PDM from concept to retirement

4. Integration/compatibility with current systems/applications

Scale:

1	2	3	4	5
PD is transferred by hand between systems; PD is stored in multiple formats/ replicated	Very little PD must be entered/ transferred by hand; data replication occurs only across functional	All internal systems are interfaced; major systems are integrated; file conversions are automatic; prime supplier file conversion is minimal	Internal systems are integrated; no PD is replicated; no manual data entry; primes, and tier 1 and 2 suppliers have PD compatibility	All supply chain PD is compatible or automatically converted both ways

Appendix B: Phase One Interview and Data Collection Tools

PDM Introduction Questionnaire – Site Level

This research, sponsored by the Lean Aerospace Initiative, is an attempt to understand the Product Data Management (PDM) efforts over the past few years and in the near future throughout the U.S. aerospace industry including how PDMs are being implemented, used, and evaluated. The goal of the research is to assist the community by adding to the knowledge being gained on PDM implementations through: 1) a better understanding of what role PDMs can and should serve in the future needs of the industry and 2) what are currently the common barriers to their successful implementation and use.

The following questions if answered before the interview would greatly help the researcher and speed the interview process. Please have this completed form available for the researcher when she comes for the interview.
Your participation in this research is completely voluntary and you can choose to withdraw at any time without penalty. Your participation is greatly appreciated by the researcher as well as the LAI community and we thank you for your time.

Interviewee Profile

1. Name ______________________________
2. Company/Division ______________________________
3. Position ______________________________
4. Contact phone and e-mail ______________________________
5. Your role and experience in relation to PDM ______________________________

____

____

____

Site Profile

6. Site name/designation ______________________________
7. Site geographic location ______________________________
8. Number of people employed at this site ______________________________
9. Does the company have multiple site locations? Yes No

   9a. If so, what are they? ______________________________

10. How many programs/projects/contracts does this site support? ____________

11. What are the major programs? ____________________________________

____

12. Is there a site-wide PDM standard tool? Yes No

    12a. If yes, which supplier PDM tool is standard? [IBM, UGS, Dassault, etc.]

    ____

Site High-Level Requirements for PDM

(Feel free to write any clarifying comments to the side.)

13. Does your company/site have a 'PDM' or 'PLM' titled position? Yes No

14. Does the site have documented processes? Yes No

15. Are these processes standard/common across the sites? Yes No

16. Are these processes standard across all programs at this site? Yes No

17. Is the site impacted by ITAR compliance policies? Yes No

18. Does your site employ Lean and/or Six Sigma practices? Yes No

Please indicate how your organization is functionally structured (there is room to write in at the bottom) and how many employees work within that function.

	Check here if this is considered a 'function'	Number of employees that work within this function
Engineering		
Manufacturing		
Business (includes finance, marketing and sales, etc)		
Supplier Mgmt & Procurement		
Quality		
Product Support		
IT		
Program Management		

PDM Introduction Questionnaire – Program Level

This research, sponsored by the Lean Aerospace Initiative, is an attempt to understand the Product Data Management (PDM) efforts over the past few years and in the near future throughout the U.S. aerospace industry including how PDMs are being implemented, used, and evaluated. The goal of the research is to assist the community by adding to the knowledge being gained on PDM implementations through: 1) a better understanding of what role PDMs can and should serve in the future needs of the industry and 2) what are currently the common barriers to their successful implementation and use.

The following questions if answered before the interview would greatly help the researcher and speed the interview process. *Please have this completed form available for the researcher when she comes for the interview.*

Your participation in this research is completely voluntary and you can choose to withdraw at any time without penalty. Your participation is greatly appreciated by the researcher as well as the LAI community and we thank you for your time.

Interviewee Profile

1. Name ____
2. Company/Division ____
3. Position ____
4. Contact phone and e-mail ____________________________________
5. Your role and experience in relation to PDM ____________________

____

____

____

Program Profile

6. Program name/designation ____________________________________
7. Program location (what site) ______________________________
8. Number of people employed by program _________________________

9. Program Focus [aerospace commercial, aerospace defense, or automotive]

[aircraft, rotorcraft, missile, launch vehicle, avionics, other, etc]

____

10. Product Deliverable ____________________

11. Product Size (parts/product) ____________________

12. Program Age ____________________

13. Program Lifecycle Phase ____________________

14. Program Budget (yearly) < $1M $1-50M $50-500M $500M–1B > $1B

15. Is there a site-wide PDM standard tool? Yes No

    15a. If yes, which supplier PDM tool is standard? ____________________

Program Goals for PDM

16. What are the program's PDM goals for 2004-2005? ____________________

____

____

Program Requirements for PDM (Write any clarifications to the side.)

17. Does the program have documented processes? Yes No

18. Are these processes standard/common across programs? Yes No

19. What % of implementation is complete/remaining? ____________________

20. What operating system do PDM clients and server(s) use? ____________________

21. What database management system is this deployment based on? ____________________

22. Does your program employ Lean and/or Six Sigma practices? Yes No

PDM Questionnaire – Site Level

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Interviewee

Name

Site Profile

1. How many programs are using/plan to use a PDM in the next 2 years?
2. How many functional organizations are using/plan to use a PDM?
3. Does this PDM implementation span multiple sites?
4. What is the organization structure of your company, and of your site? [matrix, hierarchy]

Site Vision for PDM

5. What is the company's PDM vision statement?
6. What are the site's PDM goals?
7. Are the site's goals aligned with the company's vision?

   7a. Explain any differences
8. What is the key reason that the company believed a PDM system was necessary?

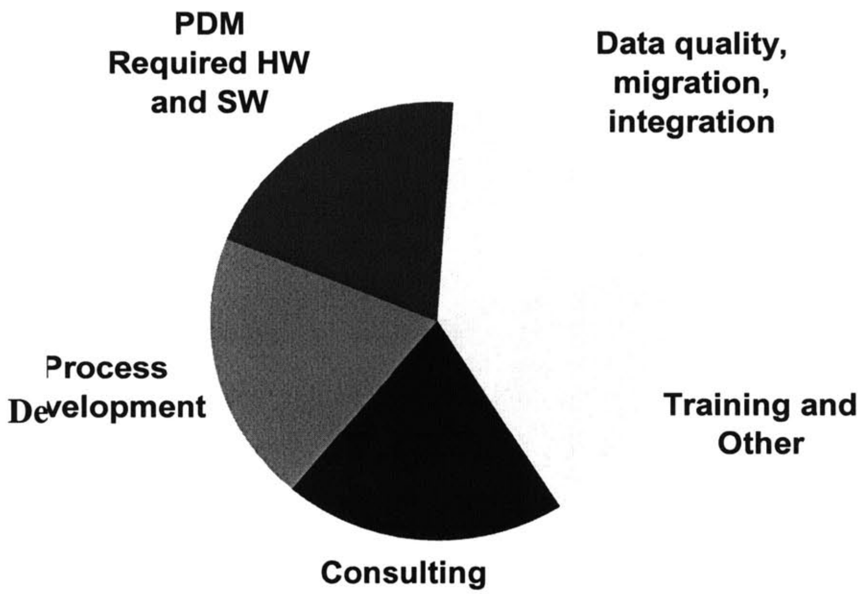
   8a. Secondary reasons? [Customer, supplier demand, internal, competitive need]
9. How has the PDM mentality or approach evolved the 2 years?

Site High-Level Requirements for PDM

Select a specific or most recent PDM deployment initiative to discuss the following questions:

10. What were the high-level requirements for this implementation? [e.g. Proliferation/replication of data, better management of complex CAD data, etc]

11. Including all resources spent over the development time frame, Program and Site, how would you characterize money spent in each of the five areas (by %)?



12. How much was/will be spent over the implementation period?

< $500K $500K - $1M $1 - 5M $5 - 10M   > $10M

13. What is the difference between the expected expenditure and the actual (in %)?
14. What was the ratio of internally driven process change versus PDM driven change?
15. Who in the organization has ownership over the processes?
16. How do you track if the documented processes are used?

Site Detailed Requirements for PDM

17. Are licenses provided individually or as a common pool?

    17a. Currently, how many licenses are provided?

18. What is the peak usage of PDM licenses? By which program?
19. Product data: <u>Volume</u>

    Internal

    External (based on what is actually being supplied (under requirements, etc)

20. How do you provide data to users in order to facilitate collaboration?
21. Was collaborative design in a virtual environment a requirement?
22. Do suppliers/partners pull the data they need, or is it provided to them?
23. How do your suppliers provide product data? [e.g. electronic, hard copy, etc]
24. How are you controlling the documents and structure that the supplier provides to you? [PDM or not PDM]
25. Did you modify your standard PDM package in any way? Elaborate.
26. Table 2 and Table 3

Implementation

27. What is the ratio of legacy systems that were shut down with this implementation? (not including visualization tools)

    27a. Can I get a copy of the system architecture/integration scheme?
28. What was the implementation approach? [Phased approach vs. big bang]

    28a. What were critical considerations in choosing the deployment strategy? [e.g. training/learning curve, number of programs to bring on board, supplier needs, etc]
29. What was the actual start and end date of this implementation? [Planning and process development; data migration and switch flip; user support and bug-fixing]
30. Did you meet your planned schedule?

    30a. If not, how many additional months did it take?

    30b. Can I get a copy of the schedule? (actual)
31. Who was the implementation planning team made up of? [e.g. IT/IS, engineering, manufacturing, PDM supplier consultants, outside consultants]
32. For deployment, what resources were used?
33. After deployment, what resources continued to be used?
34. What activities were included in preparing for this implementation? [User training, process redefinition/optimization, pilot, etc.]
35. Describe how the training was performed. Was it successful? Why or why not?
36. Did you have sufficient support and active participation from senior management?
37. How often did you "change direction" or make "significant course changes" from your goals based on unknown obstacles or cultural resistance?

38. Is there a standard process to capture lessons learned?
39. Were plans changed for the next rollout after review of lessons learned?
40. What was the most difficult implementation issue? [e.g. cost limitations, user acceptance, vendor customizations, integrations]
    40a. How was it solved? (Push cultural, political, organizational)
41. What would you do differently next time regarding the implementation process?
42. Do you have any 'objective' evidence to show your 'planned' rollout versus your actual?

Metrics

43. Was a business case prepared for the PDM? [A business decision or a technical need?]
    43a. If yes, what was the measure of the benefits? [e.g. cost avoidance, improved processes]
    43b. Was the business case verified after deployment?
44. What were/do you expect to be the key cost savings? [e.g. IT overhead, legacy maintenance, product rollout]
45. After implementation, what was the time required to achieve a positive ROI?
46. What functions of PDM provided/do you expect to provide the most user benefit/company savings?
47. What metrics is the site using/planning to use to measure the benefits or losses of PDM? [e.g. design cycle time, quality, collaboration metric, etc]
48. What metrics are available for collection?
49. Were user expectations met?

PLM

50. What do you understand to be the difference between PDM and PLM?
51. How are you approaching PLM i.e. what is the long term strategy?

Collect data on reduction in cycle time and engineering change stuff

Possible metrics: Change in time to acquire data; ability to locate any part of a product delivered by said site; elimination of hours spent reconciling replicated master definition data

PDM Questionnaire – Program Level

This research, sponsored by the Lean Aerospace Initiative, is an attempt to understand the Product Data Management (PDM) efforts over the past few years and in the near future throughout the U.S. aerospace industry including how PDMs are being implemented, used, and evaluated. The goal of the research is to assist the community by adding to the knowledge being gained on PDM implementations through: 1) a better understanding of what role PDMs can and should serve in the future needs of the industry and 2) what are currently the common barriers to their successful implementation and use.

Interviewee Profile

Name

Program Profile

1. How long has a PDM been deployed on the Program?

Program Goals for PDM

2. What is the Program's Vision Statement?
3. Is the Vision Statement aligned with the site/company?

   3a. Explain any differences.
4. What is the key reason that the Program believes that a PDM system is necessary?

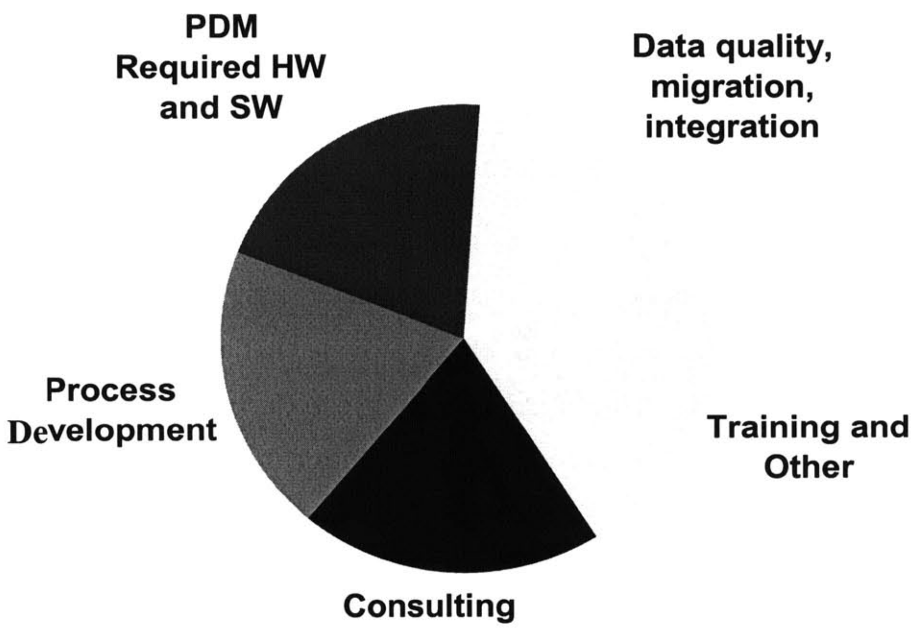
   4a. Secondary reasons? [Customer, supplier demand, internal, competitive need]
5. How has the PDM mentality or approach evolved the last 2 years?

Program High-Level Requirements for PDM

Select a specific or most recent PDM deployment initiative to discuss the following questions.

6. What were the high-level requirements for this implementation? [e.g. Proliferation/replication of data, better management of complex CAD data, etc]
7. What goals were set for this implementation?

8. Including all resources spent over the development time frame, Program and Site, how would you characterize money spent in each of the five areas (by %)?



9. How much was/will be spent over the implementation period?

   < \$500K $500K - $1M $1 - 5M $5 - 10M > $10M

10. What is the difference between the expected expenditure and the actual (in %)?
11. Who in the organization has ownership over the processes?
12. What was the ratio of internally driven process change versus PDM driven change?
13. How do you track whether documented processes are used or not?

Program Detailed Requirements for PDM

14. How many instances of your database do you have?
15. Is any PDM-managed data replicated in other systems?
16. Are licenses provided individually or as a common pool?

    16a. Currently, how many licenses are provided?

17. How many user roles are defined in the PDM system for the Program?
18. Do the external users use the same system as internal users?

18a. What type of connection is used? [dedicated line, internet]

18b. Does the Program provide the service?

19. How does the Program restrict user access to only product data necessary for them to see?

20. Product data: <u>Volume</u>

    Internal

    External (based on what is actually being supplied (under requirements, etc)

21. How do you provide data to users in order to facilitate collaboration?
22. Was collaborative design in a virtual environment a requirement?
23. Do suppliers pull the data they need, or is it provided to them?
24. How does your supplier provide product data? [e.g. electronic, hard copy, etc]
25. How are you controlling the documents and structure that the supplier provides to you? [PDM or not PDM]
26. Did you modify your standard PDM package in any way? Elaborate.
27. Table 2 and Table 3

BOM

28. Are the Engineering Bill of Material view and the Manufacturing BOM view in the PDM? Are they two distinct entities or one in the same?
29. Is the As-Supported Bill of Material view used on the Program, in the PDM?
30. How does the PDM address EBOM effectivity? [No scheme, with date effectivity, with unit eff]

    30a. If tracking effectivity, is it linked by child component, or by child-parent relationship component?

Implementation

31. Is this the first PDM implementation on this Program?
32. What is the ratio of legacy systems that were shut down with this implementation?

    32a. Can I get a copy of the system architecture/integration scheme?

33. What was the implementation approach? [Phased approach vs. big bang]

    33a. What were critical considerations in choosing the deployment strategy? [e.g. training/learning curve, number of programs to bring on board, supplier needs, etc]

34. What was the actual start and end date of this implementation?
35. Did you meet your planned schedule?
    35a. If not, how many additional months did it take?
    35b. Can I get a copy of the schedule? (actual)
36. Who was the implementation planning team made up of? [e.g. IT/IS, engineering, manufacturing, PDM supplier consultants, outside consultants]
37. For deployment, what resources were used?
38. After deployment, what resources continued to be used?
39. What activities were included in preparing for this implementation? [e.g. User training, process redefinition/optimization, pilot, etc.]
40. Describe how the training was performed. Was it successful? Why or why not?
41. Was there a standard process to capture lessons learned?
42. Were plans changed for the next rollout after review of lessons learned?
43. Did you have sufficient support and active participation from senior management?
44. What was the most difficult implementation issue? [e.g. cost limitations, user acceptance, vendor customization, integration] [Probe political, cultural, organizational]
    44a. How was it solved?
45. What would you do differently next time regarding the implementation process?

Metrics

46. Was a business case prepared for the PDM? [A business decision or a technical need?]
    46a. If yes, what was the measure of the benefits? [e.g. cost avoidance, improved processes]
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47. What were/do you expect to be the key cost savings? [e.g. IT overhead, legacy maintenance, product rollout]
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49. What functions of PDM provided/do you expect to provide the most user benefit/company savings?
50. What metrics is the site using/planning to use to measure the benefits or losses of PDM? [e.g. design cycle time, quality, collaboration metric, etc]

51. What metrics are available for collection?
52. Were user expectations met?

PLM

53. What do you understand to be the difference between PDM and PLM?
54. How are you approaching PLM i.e. what is the long term strategy?

Collect Metrics

Possible metrics: Change in time to acquire data; ability to locate any part of a product delivered by said site; elimination of hours spent reconciling replicated master definition data

	Tool Used (PDM, ERP, COTS, HG (homegrown))	Part of Product Master Definition (Yes or No)	Where Data is Managed Now (PDM, ERP, CM, non-CM)	Where Previously Managed	Where Planned to be Managed
Modules	-	-	-	-	-
Product Structure		-	-	-	-
Document Release Management (includes Electronic Approval, etc.)		-	-	-	-
Workflow Management		-	-	-	-
Visualization		-	-	-	-
Change Management		-	-	-	-
Vaulting		-	-	-	-
Collaboration		-	-	-	-
Product Definition	-	-	-	-	-
Engineering Data	-	-	-	-	-
CAD 2D	-				
CAD 3D	-				
Scanned Drawings	-				
CAE (Patran, Nastran, etc.)	-				
Engineering Notes					
Non-conformance Data	-				
Structural Analysis Data, Stress Notes	-				
EBOM	-				
Manufacturing Data	-				
Tooling Design Models	-				
MBOM	-				
Other	-	-	-	-	-
Procurement (POs, etc)	-				
Program Management Data (e.g. Contracts)	-				
Meta Data (e.g. Specifications)	-				
Flight Test Data	-				
Quality Data	-				

Field Data	-				
Maintenance Data	-				
Schedules	-				
Other Support Function Data (Budget, Cost, etc)					

Table 2. PDM utilization and population by functional organization

Internal Functional	User Creates PDM Data	Inquire Against PDM Data	How many named users (Create/ Inquire only)	% of total population type integrated into PDM environment
Engineering				
Manufacturing				
Test				
Quality				
Supplier Management & Procurement				
Product Support				
IT				
Business (finance, marketing, sales, etc)				
External				
Partners				
Tier 1 Supplier				
Tier 2 Supplier				
Customer				

Table 3. Integration technique between PDM and other major systems

	Integration technique				
Tool	Tightly coupled	Loosely coupled	Flat files	Replication	Manual
ERP					
MRP					
SCM (Supply Chain Management)					
Legacy PDM ________					

Appendix C. Process Interview Tool

Process Questionnaire

Interviewee Contact info:

Name ______________________________

Company/Division ______________________________

Position ______________________________

Contact phone ______________________________

Contact e-mail ______________________________

General Questions:

1. Who in the organization has ownership over the processes?
2. What was the ratio of internally driven process change versus PDM driven change?
3. What processes are being driven and why?

5 Steps: Ask for examples, documentation, etc

4. Were stakeholders identified?

   4a. Who are/were they?
5. Was the stakeholder value identified?

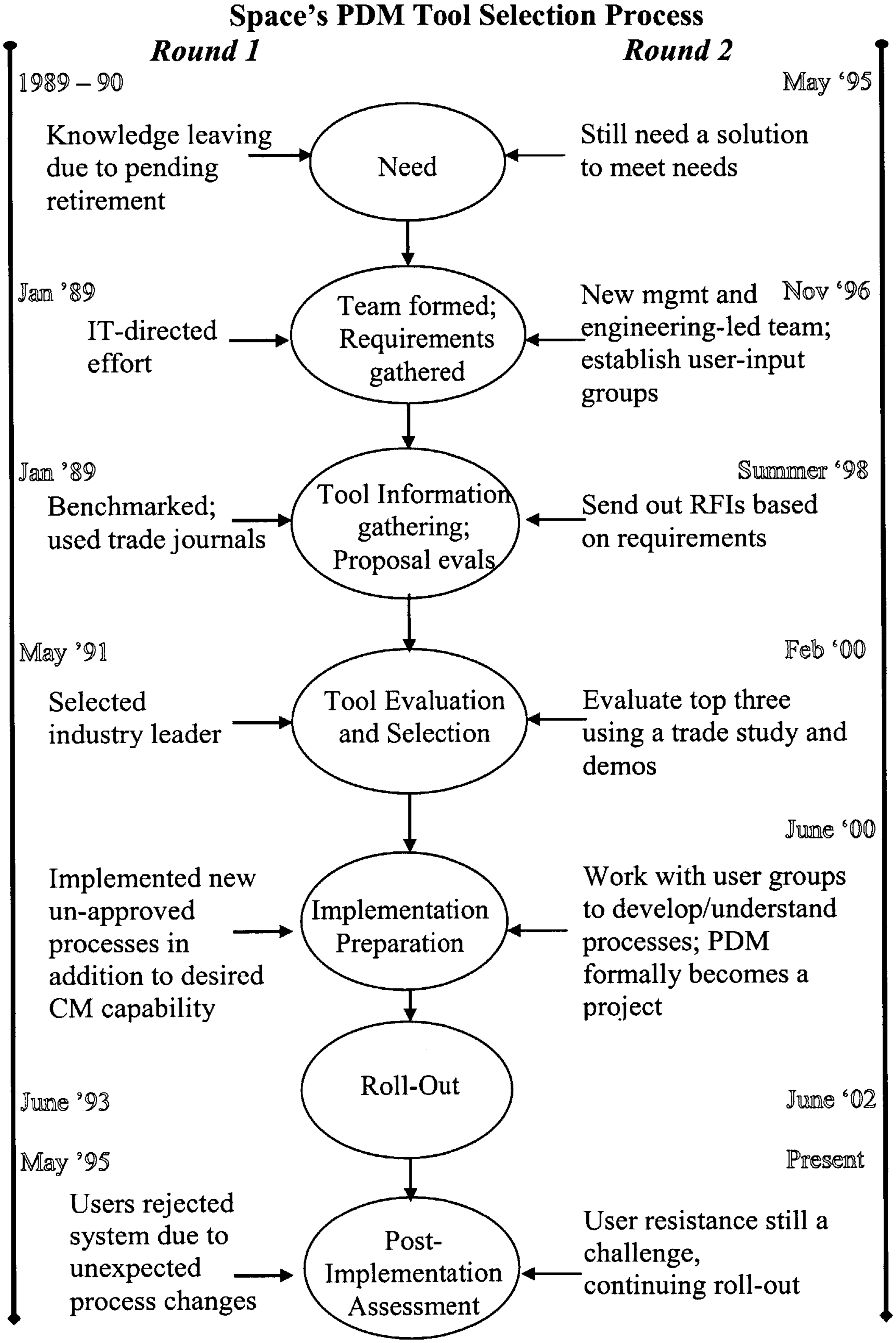
   5a. What is an example of the value they expected/wanted?
6. Were the old processes evaluated and new processes developed based on delivering the value identified?

   6a. How? [Did they ID waste, areas of change, etc?]
7. Was a change implemented?
8. Did the change meet expectations?

   8a. Was it successful?

   8b. Why or why not?

Appendix D. Case Study Site Process Diagrams for PDM Tool Selection



Aero's PDM Tool Selection Process