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The Small and Medium Enterprise's Perspective of Product Data Management

Karen Waldenmeyer

Purdue University - Main Campus, karen.waldenmeyer@gmail.com

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For the degree of Master of Science

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THE SMALL AND MEDIUM ENTERPRISE'S PERSPECTIVE OF PRODUCT
DATA MANAGEMENT

A Thesis

Submitted to the Faculty

of

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Karen Waldenmeyer

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ABSTRACT

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This study was conducted as a means to discover common traits associated with small and medium manufacturers, especially ones who have adopted product data management systems as a method to control engineering design and manufacturing data. After qualitative interviews with leading experts in the PDM field, a survey was developed and sent to small and medium manufacturers in the United States. The survey concludes a number of interesting statistics about the state of PDM usage within this segment of the industry, including general uses for engineering design systems, level of data exchange with customers and suppliers, and satisfaction levels with information querying, concurrent engineering contributions, and imposed restrictions. The study concludes that there are a few major factors that determine a company's success with using design systems, including frequency of data exchange, data reuse, digital data formats used, and employee counts and locations.

CHAPTER 1. INTRODUCTION

1.1. Background

Small engineering firms usually operate in challenging environments – many are subject to the whims of their customers, who are typically larger, more well known manufacturers (Towers & Burnes, 2008). This changes the normal design process model, where the company must “talk to customers” and make sure they are producing a product “that customers want.” Instead, these small and medium enterprises (SMEs) are usually given very specific details that their product must conform to in order to meet their customer’s specifications (Arendt, 2006). Sometimes this requires SMEs to be very flexible in their design tools, based on how many different customers they are serving.

Products are increasingly being designed with three dimensional (3D) tools that enable a host of different analyses, simulations, and design changes. Unfortunately, the software that enables this new design methodology is not nearly as accessible to SMEs as it is to larger, more robust manufacturers. While their customers most likely have created the requisite network infrastructure for their 3D data due to the fact that the sheer volume and breadth of their data necessitated it, many SMEs have not yet adopted any formal strategy for managing the data for their own smaller, but still complex design methods. This inexperience in 3D tools and data management constitutes a great opportunity to talk to SMEs, discover what their needs are, and to possibly make recommendations on which tools are currently available that could make them much better at their core business goals. This idea is the main thrust of the proposed thesis.

The main research interest of this thesis is in product data management (PDM), which is a technology that seeks to manage, secure, control, and accelerate the engineering process by ensuring that all data, particularly 3D data, is stored in one easily accessible and manageable location. Many PDM systems can be difficult and costly to install and implement, particularly in SMEs that have limited resources and potentially higher vulnerability to implementation failures (Chen, Huang, Yang, Lin, & Chen, 2007). Along with these systems come many organizational changes to which SMEs may be unaccustomed, such as increased collaboration between areas of the business and entities outside the business, but because of their smaller size, these companies may be more flexible in the way they run their business.

1.2. Research Question

What are the common traits of small manufacturing businesses that have adopted a digital product data management (PDM) system, and how has this PDM technology affected them?

1.3. Significance

Small and medium enterprises (SMEs), typically classified as employing less than 500 people, employed approximately 6.1 million US citizens in 2006 in the manufacturing industry alone (“Statistics about Business Size from the Census Bureau,” n.d.). At the same time, SMEs have to compete for resources and market share in a manufacturing industry that is struggling to stay afloat in the tough economic environment of 2008-2010. Manufacturing SMEs are in a particularly unique situation due to their limited resources, their increased level of flexibility, high amount of personal relationships within the company, and relatively low levels of bureaucracy, among other things (Marri, Gunasekaran, & Grieve, 1998). These companies have been relatively slow to adopt new design technologies like 3D CAD, product lifecycle management (PLM) philosophies,

and product data management (PDM) technology. There are many manufacturing and design SMEs in business today that still have not updated their systems and processes for many reasons such as cost, having simpler product lines, or simply not needing to because of the specific product or product lines that they manufacture and sell. However, many of these SMEs are moving towards new methods of product design by doing the bulk of the design work in 3D CAD tools, and it would be helpful to pinpoint the exact reasons why these organizations are updating, and what kind of success they are having.

By pinpointing these reasons and examining some of the experiences these SMEs are having in regards to implementing PDM technology, we can begin to build a better picture of the SME that is trying to survive in a complex product design environment. From this picture we can start to draw conclusions and give recommendations to those SMEs who are considering moving to a data management system that handles their 3D CAD files, so as to ensure the process goes as smoothly as possible. As previously stated, a significant percentage of the US population is employed by a small or medium sized manufacturer, and could potentially be affected by a failed implementation of a PDM system. Therefore, especially in today's economic climate, identifying problem areas for SMEs and finding solutions to their problems benefits their industry as a whole.

Since manufacturing SMEs vary in terms of technology adoption and use, it is important to put few restrictions on which ones are part of the survey sample. It is crucial, however, that SMEs have a history with product data management theories and practice. This represents taking the next steps from just designing using 3D CAD programs – it means managing that 3D data along with other product data in a useful, profitable way throughout the whole product lifecycle, from product ideation to disposal or recycling. To this end, it requires a certain level of sophistication on the part of the SME, because this newer method of designing products can be relatively difficult for a smaller company that sometimes suffers from micromanagement on the part of upper management.

However, product lifecycle management methodologies have been in practice in larger companies for years, and have now trickled down to many smaller companies, many of which are suppliers to the larger corporations. This is partly due to an easier access to digital technology which enables the design process to go faster, but also from a change in mindset about how a manufacturer should think and produce products. PLM encourages an organization in the manufacturing business to look at its work in terms of a product, instead of a process (Ameri & Dutta, 2005). This usually means a reorganization to distance itself from a “departmental” environment where each department is like an isolated island and communication is deemed “over the wall” to a newer, more flexible design process that focuses on a single product or family of them, with specialists from different backgrounds collaborating together from the beginning of the product’s design phase all the way through its disposal (Sääksvuori & Immonen, 2005). Thus, it is useful to get a better picture of what drove manufacturing SMEs to make such drastic changes to their business processes, adopt new PDM technology to manage all the newly generated data, and how it went. This can be a good resource for small companies in the future who want to go down the same route to remain competitive in their industry.

1.4. Scope of the Study

Because there are a variety of different factors that drive small and medium businesses to implement digital systems to improve their business processes in general, it is important to put some constraints on what this research study will investigate specifically. For the purposes of this study, a small or medium business will be defined as a US-based company that has less than 500 employees on its payroll – regardless of the level of revenue or profits the company currently makes (Ayyagari, Beck, & Demirguc-Kunt, 2007). This is due to the study’s focus on the human perspective of how product data management has affected smaller businesses, instead of company monetary success (another way of defining SMEs) or product complexity. These companies of less than 500

people must be in the business of manufacturing or otherwise designing products, because this is critical to finding out why they implemented a digital product data management system. They must also be headquartered and incorporated in the United States, to decrease possible issues related to language barriers in the study, as well as to avoid problems related to different business laws and regulations and information export. All companies in the sample will be utilizing digital design software, either 2D or 3D, from any software vendor as part of their design process. However, the degree to which it is used will not have limitations due to these companies' wide variety of experience with CAD and PDM technology and company size. The companies in the sample also may have implemented a digital PDM system, but again there will be no restrictions on the complexity of the PDMS, the specific vendor, nor the amount of use in daily design activities. Companies that respond to the survey that do not have a PDM system will also be studied to see if there are any relationships between company characteristics and the simple fact of having implemented a digital design system or not. The study will be aimed at as many companies that meet the above criteria as possible.

Survey questions were generated after interviews with four experts in this specific field of information technology and manufacturing were conducted, in an effort to streamline survey questions to provide the best picture of how SMEs are handling PDM and ensure the survey asked appropriate questions. Companies participating in the larger online survey were asked questions about the basic nature of their business in terms of industry and employee counts. Also, they were asked specific questions about their suppliers, customers, information technology integration, and company culture. Companies were also asked specific questions about the level of penetration the PDM system has made into the company's daily business activities, and their experience with its implementation. All these aspects of the company have direct effects on the product design process, and consequently on the implementation of a product data management system (PDMS), whether it be successful or a failure. From a

sampling of a homogenous population of small and medium sized companies, some conclusions can be made about the current trends in PDM implementation for SMEs, and how to improve the experience of companies looking to implement PDM in the future.

1.5. Assumptions

The assumptions for this study will include:

- There is a need to understand which business characteristics make small and medium manufacturers utilize digital product data systems.
- All respondents will provide accurate information regarding characteristics of their company (classified as an SME, considering or are starting PDM, etc) through survey questions and in interviews.
- All participants are allowed to disclose the information about their company that they are asked to disclose.
- All participants are knowledgeable enough about engineering design and product data management to answer questions completely and thoughtfully.

1.6. Limitations

The limitations of this study will include:

- This study will be limited to participants from the pool of contacted SME manufacturers.
- This study will be limited by the methods of contact used to gather information from SMEs.
- This study will be limited by the time constraints of participants in the qualitative preliminary interviews.

1.7. Delimitations

The delimitations for this study will include:

- This study will not use data from a manufacturing business with more than 500 employees currently on payroll.
- The manufacturing businesses in this study will be incorporated in the United States. They may have satellite offices in other countries, but their base of operations must be within the borders of the United States of America and its territories.
- Participants will not have more than approximately two weeks to respond to the online Qualtrics survey.
- The preliminary interviewing period will not exceed one month to give participants and the researcher adequate time to conduct interviews.

1.8. Definitions of Key Terms

SME – “A unique definition of SMEs is not possible, the concept varies from country to country and from sector to sector. However, in terms of the structural funds and leading instruments of the EU, it has always been accepted that the SME should not have a workforce exceeding 500, or net fixed assets of more than a third of the capital held by a large firm.” (Marri et al., 1998, p. 936)

PDM – “Product Data Management (PDM) systems are about managing product information, throughout the entire lifecycle of a product, in a more efficient, organized way.” (Siddiqui, Burns, & Backhouse, 2004)

PLM – “As an extension, PLM (Product Lifecycle Management) systems introduce project management functionalities (Saaksvuori and Immoen, 2004). Actual PLM systems integrate Internet-based technologies and offer groupware-like functionalities (Johansen, 1998, Eynard and al., 2002).” (Pol, Merlo, Jared, & Legardeur, 2005)

CAD – “Computer-aided design (CAD) is a widely used tool for product design.”
(Tan & Vonderembse, 2006)

Product design – “the process used to create new products, such as a new automobile model, a new appliance, or a new type of wheelchair. Product design is a complex activity that includes market, production, sales, service, function, and profit analyses. The goal of product design is to produce a product that meets the wants and needs of the consumer, is produced economically, is safe for the consumer and the environment, and is profitable to the company.” (Bertoline & Wiebe, 2005)

Relational design – “In a relational model, each design object is described by variables and relations. Variables represent the object’s properties, and relations, its behavior.” (McCullough, Mitchell, & Purcell, 1990)

Configuration management – “product definition information in the sales-delivery process for fast and correct configuration of working product variants that fulfil customers’ requirements and company constraints such as production and delivery capabilities.” (Mesihovic & Malmqvist, 2000)

Product workflows – “Workflows are collections of human- and machine-based activities (tasks) that must be coordinated in order that groups of people can carry out their work.” (Kovacs, Le Goff, & McClatchey, 1998)

Version control – “Version control ensures all changes to data are stored with a history.” (Iuliano, n.d.)

Revision control – “Revision control ensures the proper versions of component data elements are combined in a meaningful way.” (Iuliano, n.d.)

Engineering change – “an engineering change (EC) is a modification to a component of a product, after that product has entered production.” (Wright, 1997)

1.9. Chapter Summary

This chapter outlined the problems small and medium enterprise often encounter with product data management, the proposed research question and its scope and significance, as well as the assumptions, limitations, and delimitations. The chapter concluded with definitions of key terms. The next chapter will outline some of the existing literature about small and medium enterprise and their relationship with product data management as a mode of engineering design.

CHAPTER 2. REVIEW OF LITERATURE

2.1. Characteristics of the Small and Medium Enterprise

This literature review endeavors to explore why small and medium enterprise (SME) have difficulties properly integrating new information technology (IT), specifically for product design, into their existing business model. There is a variety of literature and studies of SMEs worldwide and their struggles and successes with implementing information systems that utilize current technological abilities and data storage. This can also be generalized to larger enterprise, specifically manufacturers, but it is of particular interest to focus on SMEs for many reasons. One of the most obvious reasons is that SME accounts for a fair proportion of the workforce. The UK, where some of the following studies were conducted, had about 44% of its workforce, or approximately 11 million citizens, employed at a company with less than 500 employees at the start of 2007 (“Small and Medium Enterprise Statistics for the UK and Regions,” n.d.). Similarly, the US had approximately 58 million citizens employed by a company with less than 500 employees in 2004 and approximately 6.1 million citizens employed specifically by a small or medium manufacturing business in 2006 (“Statistics about Business Size from the Census Bureau,” n.d.). It is clear that a large number of people are affected every day by small and medium business, and if SMEs succeed, a sizable segment of the economy will prosper.

So what can we learn about SMEs that could help us make them more successful? It is important to understand some of the unique business realities that SMEs face every day when compared to larger companies. The first and foremost issue these smaller enterprises face is their lack of resources. They tend to lack the monetary and human resources to stay on top of their IT systems

and ensure that they are up to date and helping enable business processes (Wickramasinghe & Sharma, 2005). Typically SMEs do not have the manpower or time to even stay current on technology trends to see if there is some new development that could directly benefit them, let alone be able to invest time into doing research into new technologies. This can put them at a disadvantage with their competitors who are continually improving and updating their design process and data management systems. SMEs are also vulnerable to management pet projects, resistance to change, lack of experience with updating technology and information systems, and being especially at the mercy of their customers, many of whom are larger OEMs (Taylor & DaCosta, 1999). However, with these vulnerabilities come other strengths and advantages they may have on their larger competitors: they are usually more flexible in terms of information system management; they generally have less complicated design processes, which necessitate less complicated software solutions and speed up planning and implementation time; and they are usually more locally placed so face to face meetings and groups are more possible and can be more effective.

2.2. Innovation and New Technologies

There are many technologies available that can enable innovation in SMEs and foster a successful business environment, but these smaller firms have more obstacles to overcome before they can utilize such tools. The advent of 3D CAD and CAE/CAM tools have enabled companies of all sizes to start designing products in 3D space, which adds a host of different possibilities to what companies can then do with that 3D data (Tan & Vonderembse, 2006). It is now possible to push 3D data into analysis programs to test strength, durability, and watch for potential failure points in a new product. The same 3D model can also help generate costing and financial planning data. It can also be used in marketing and advertising campaigns. More and more companies are moving to 3D product design, and software vendors who write, maintain, and license CAD programs are increasingly making this technology available to the SME

customer, who has fewer expectations of their CAD system and need it for a lower price (“PLM for the SME,” 2004).

However, with all this 3D data come data management issues. This is where some SMEs are right now – they have a few seats of CAD software, and could be generating hundreds of parts and assemblies a year, but if not implemented correctly, innovation can stop there. Studies of manufacturing SMEs in Brazil by Kaminski, Oliveira, and Lopes in 2008 showed that very few SMEs in even the most industrialized part of Brazil use CAD at all, and far fewer employ any of the above stated technologies to further benefit from those models. SMEs in particular need simple solutions to managing all their CAD data and getting the most value from it, especially if they want to use another of the available technologies previously mentioned.

One major tool for product development has become a product data management system (PDMS). These are systems that effectively store and manage product data during the product’s lifecycle, adding meaning to the chaos that can sometimes happen during the design process, especially concurrent design. PDMS are built to handle engineering design changes and deal with product variants, as well as track product structure and of course, manage bills of materials.

Too often SMEs and their senior managers in particular, are sold a well-choreographed presentation by a software vendor that convinces them the system in question will solve their product development problems and increase profits. When the software gets to the manager’s desk, though, it typically does very little of what the vendor advertised, for a variety of reasons. This is often because an implementation of a system as sophisticated as a PDMS usually requires a sizable time investment in the research of business practices currently in place, as well as strong management support for the new changes that need to happen, and a culture of education to show non-management employees why the new system will eventually make the company even more successful than it currently is (Siddiqui et al., 2004). However, many of these aspects can be

overlooked in an SME that is trying to implement these new systems on top of its already usually stressed workload.

2.3. Management Characteristics

One of the major failing points of PDMS and CAD technology in general in SMEs typically comes from managers' lack of support or ignoring suggestions made by the software vendors on how to best utilize the software. This is best characterized in a study conducted by Walters (2007) on the effectiveness of CAD implementation in an SME manufacturer specializing in yachts. When the owner/manager decided it was time to use a CAD system for design, he created a detailed list of requirements that the CAD system had to meet, and in conjunction with Walters and his university, selected and bought two seats of the CAD software. The CAD vendor recommended to the owner that he model all parts and create a library of them. Although this would not provide immediate return on the investment, it would eventually lead to more successful 3D usage in the future. The owner disagreed, and instead tried to model a system on a boat that had already been installed because he insisted this would help the company "get ahead" on the models for the next boat in the product line. This approach ended up failing because the installed physical parts of the boat differed significantly from the designed drawings, and the owner misunderstood the assembly process as being linear when in reality it was nonlinear due to fit issues (Walters, 2007).

This is just one example of how management understanding can negatively affect the implementation of a new design technology. SMEs tend to implement technology in a way that causes the least amount of change and challenge to the existing power structure (Lee, Bennett, & Oakes, 2000). This could be due to many factors. One main factor could be the sometimes overbearing methods of the managers and owners, which in an SME's case can be far more powerful than in a larger organization with more bureaucracy. Senior managers tend to have more influence in SMEs and so these smaller

organizations are more prone to managers' pet projects and whims, which sometimes leads to technical decisions being made by someone with a nonexistent or outdated technical background. Sometimes these same managers have no knowledge of newer technologies at all, and are therefore resistant to adding new technology to the mix just because of their lack of familiarity with the process and software possibilities themselves (Thong & Yap, 1995)

2.4. Resistance to Change

Change is another frightening prospect to many SMEs, and this is especially apparent when user support for a new technology is lacking. CAD systems and PDMS symbolize a fundamental change in the way an organization structures their design practices – with a PDMS, the old ways of “over the wall” engineering are supposed to disappear. This is because PDMS are designed to be concurrent in nature, with several people from different departments working on one single product at any one time. This means that the manufacturing engineer sees the product while it is in the design phase so that he or she can point out potential problems or issues early in the process, thus saving development time and cost. PDMS were developed with this goal in mind, where a product is essentially designed inside the system, with multiple people from all different areas of the company coming together to design the product efficiently. In theory it sounds like an easy and practical change to make, but it can be very difficult for SMEs in particular to adopt this new way of thinking about product design because it requires them to change their daily activities and tasks, as well as work closely with other employees they previously had little or no contact with (Walters, 2007). There may also be emotional fears due to an automated process because of the potential for job redundancy, and employees may believe the success of a new PDMS will mean the end to their job completely. This suspicion can, in the very worst instances, lead to direct tampering in the PDMS implementation process, or at best create a negative

attitude which the employee continues to carry with them that may affect future job performance (McGrath, 2006)

All these factors can lead to dissatisfaction with the PDMS, both from upper management who is directing the implementation, all the way down to the end user whose daily work tasks will be dramatically changing with the addition of a system they must use for hours each day. When end users are unhappy with the PDMS, major problems in the design process can occur, such as users attempting to circumvent or otherwise compromise the system, effectively breaking the design process and potentially causing stress and extra expense later on in the product's lifecycle.

2.5. Investment in Information Technology

Despite these hardships, studies have shown that investment and involvement in IT projects like implementing PDMS and other business-related systems like enterprise resource planning and customer relationship management, have a positive effect on the SME that endeavors to constantly improve its products and its processes (Dibrell, Davis, & Craig, 2008). A common theme that appears is an SME's ability to align its IT processes and usage with its business goals, suggesting that a company who cannot do this over a long period of time will eventually fail to meet its customer's requirements. This brings up another unique trait that many SMEs have in common, in that many are actually suppliers to larger companies. In fact, in Thomas, Barton, and John's 2008 study of 300 different UK SMEs revealed that 111 of the companies were classified as original equipment manufacturers, and the rest would be deemed as suppliers to other companies (Thomas, Barton, & John, 2008). What does this mean for SMEs around the world? Not only are these small organizations under pressure from the market and competition to be able to produce the best product, but their customers may very well have specific technology requirements that the SME must meet to even be considered as a supplier. That means that an SME with limited IT staff might be required to maintain several different CAD

packages, and other associated systems to handle the 3D data in the manner their customer is requiring. That can put a lot of pressure on SMEs to implement a particular technology fast, but unfortunately they do not always have the best resources at hand to make it happen.

After speaking to some of the broader issues that SMEs face on the engineering data front, it is useful to talk about some of the more specific problems related to information management in these smaller organizations. A major issue and possible stumbling point is having a good knowledge of information flow, both within the company and external to the company (Hicks, Culley, & McMahon, 2006). SMEs can sometimes overlook the complexity of the data itself, or underestimate the sheer amount of effort it can take to map the path of one piece of data as it flows from one person to another, out of the organization, and back in, as well as what other pieces of data can be interconnected to it. However, a lot of this work is needed to adequately implement a PDMS or any other business process related piece of software that is going to house data and make sure it gets to the proper people at the right time in the correct format. According to Hicks et. al (2006), the number one concern of engineering SMEs is the exchange of information and the added chore of data entry into a new PDMS or other such system. While this is a major concern and can make using systems like the ones previously mentioned very difficult, it represents a fundamental misunderstanding on the part of the SMEs about the way the systems are supposed to work. PDMS serve as a central data repository, and when implemented and used correctly, are supposed to drastically cut down on the amount of data reentry and ensure consistent information exchange between people, departments, and companies. However, because these are chief concerns of engineering SMEs, their use of PDMS and other systems thoughtfully could lead to very high returns on their investments.

2.6. Inherent Advantages

Despite all these possible problems SMEs face when considering going to a product-centric design process and implementing a PDMS and its associated systems, SMEs are also a fascinating case for PDMS and model-centric design success. One reason for this is an SME's inherent flexibility due to their small size and relatively small number of requirements when compared to a larger corporation with thousands of employees and hundreds of products and product variations (Levy & Powell, 1998). This is a very positive aspect that SMEs can look forward to when contemplating upgrading their business and design processes. Typically SMEs have less data and fewer requirements to deal with, and making the switch to a digital system of storing and managing data ends up becoming an asset in the long run. With software vendors increasingly making commercial software more accessible for the forward-thinking SME, it is relatively easier to implement these kinds of advanced data systems than it was ten or fifteen years ago. Software vendors are even in the process of making their systems easier to upgrade and effectively "grow" with the company's needs, thus making the option to update processes even more attractive.

2.7. Specialized PDM

Much work has been done in customized PDM solutions that are tailored specifically for the needs of an engineering PDMS. Because these systems are meant to reflect the business practices and processes that already happen in an organization, it is often helpful to map out what the SME is currently doing to design and improve on products, then define what a PDMS must do to meet those needs as a baseline. Mi, Shen, and Zhao (2005) described such set of requirements and a new system for SMEs to implement a collaborative design environment that is meant to be used concurrently between all aspects of the design team. They are quick to stress the fact that SMEs are best served by a commercial software solution because of the relative ease of install and use, while recommending a web-based system composed of different modules for

different types of functionality in the design process. Their system design is just one of many possibilities, and would probably change depending on the needs of the SME to which it was going to be applied. It is important to remember that whatever system a company implements must be able to effectively work in concert with the organization's existing systems, or replace them altogether in an effort to obtain a more elegant solution (He, Ming, Ni, Lu, & Lee, 2006). This is why such a large investment of time and resources must be made at the outset of the implementation project – planning is key in making sure that the new system will be successful and provide an adequate return on the initial investment and ongoing costs of maintaining the system.

Most larger corporations who have been practically forced to implement similar PDMS simply due to the scale of their data and system needs have appeared to benefit a great deal because it has enabled them to stay more in touch with their customers while cutting down on design and other costs. Because SMEs are in the unique position of having lower staff numbers, many are now turning to technology to help cut costs and increase profits without adding additional workers. PDMS have been the method of choice for larger OEMs, and many SMEs are looking for quick fixes to immediate budgetary problems as well as long term options for maintaining their current business and growing into new sectors. Studies have shown that the ones who are investing thought, time, effort, and money into these new options generally have a better chance of success (Lee et al., 2000).

For many of the reasons mentioned in this brief review of literature, SMEs are an intriguing study in the success and failure of 3D CAD systems and product data management systems. They have their own unique disadvantages when compared to larger manufacturers, while also having an edge on those competitors in other regards. However, in recent months the economic climate around the world has changed significantly, and it would be interesting to see how SMEs in particular are dealing with these challenges in respect to their design processes and data systems. Since these small companies practically

form the backbone of the manufacturing and other industries, it is important that we study what their needs are and how we can best meet those needs with technology to help bring these resource-lacking companies into better harmony with their customers and with the greater industry to remain competitive.

2.8. Chapter Summary

This chapter summarized the literature that exists on the study of small and medium enterprise, their unique qualities, and how product data management affects them at different levels. It also discussed some of the existing literature for studies utilizing grounded theory and mixed method research. The next chapter will detail the hypotheses for the study, as well as the methodology that will be followed and the projected timeline associated with it.

CHAPTER 3. STUDY METHODOLOGY

3.1. Introduction

How do we go about discovering what common business characteristics drive a small business to implement a digital product data management system? It is important to keep the scope and significance in mind as we go about defining the problem and fleshing out the methodology to find the answer to this question. The companies polled during the research study need to fit a few broad criteria: all companies must be designing products for manufacture digitally, have less than 500 employees, and have recently installed a PDM system or may be going through the process soon. By surveying as many SMEs with these characteristics as are willing, it is possible to form some conclusions on what the common factors were, such as product complexity and customer demands, that made them move to a digital product data management system, as well as how they are handling all the necessary work that goes along with an implementation of these systems.

3.2. Research Type

As previously stated in the review of literature, there is a great deal of research in the fields of SME and IT, as well as an almost equally large amount relative to PDM and product lifecycle management. However, none of the studies that employ a large survey of SMEs have been conducted with companies in the United States. However, we can still deduce some basic facts about the majority of SMEs in the US. They tend to have fewer resources than larger firms, both in labor potential as well as monetary and time resources. They also sometimes have managers and owners that are more involved with the daily running of the

business than larger organizations, which can be an advantage as well as a disadvantage, depending on the management style of those in charge. They do often attempt to invest in information technology, but they usually do it more cautiously because the risk of a failure is greater to the existence of the company itself than it would be to a larger business. Despite these potential obstacles, SMEs are usually more flexible and it is easier and sometimes faster to affect organizational and technological change, if employees are truly “on board” with the planned change. This is one of their best strengths when compared to larger companies that may be more culturally open to change but slow to actually implement change for a variety of reasons. There are also more and more specialized options for SMEs’ specific PDM needs which address their smaller scale but complex product design and collaboration needs. Research with IT implementation of these types is increasingly taking a mixed methods approach by using case studies and interviews along with grounded theory to interpret a set of findings and create theories or relationships based on what was recorded from the qualitative data. SMEs are also often surveyed using quantitative methods as well, though there have not been any large surveys of this type given to manufacturing SMEs based in the United States.

This study uses mixed-method data collection. This is due to the complex nature of the research question being asked, and the number of variables involved. Because the subjects are companies, which even on a small scale can be incredibly complex, a combination of preliminary qualitative feedback and quantitative survey methods is the most useful strategy to employ. The study consists of four preliminary qualitative interviews with targeted PDM subject matter experts that will cover broader PDM issues relative to their communication with suppliers and customers, and how PDM technology has affected them. From these interviews, a quantitative survey was developed that asks questions drawn from the preliminary interviews. Questions in the quantitative survey include Likert scale answers and multiple choice questions (with room for an answer “other” not already specified), as well as a open answer questions. The

responses to these questions illustrate any positive aspects of PDM implementation that small companies benefit from, as well as the elements that they may tend to have more difficulty getting through. From these responses, conclusions will be made in terms of what a majority of small companies are experiencing relative to PDM implementation and usage.

3.3. Interpretive Research and Mixed Methods

Grounded theory approaches have historically been used to help researchers develop concepts and theories based on qualitative data (Glaser & Strauss, 1967). Because of the lack of research into SMEs in the United States, and due to the nature of the data beginning as qualitative and then being interpreted into questions that will produce quantitative data, it is necessary to discuss the peculiarities and general nature of this type of research, which will take an interpretive approach based on the fact that there are no existing theories on how SMEs are currently dealing with product data management issues. Interviews typically are part of most studies that involve interpretation in some way – in the current study, it will be used to create survey questions for the second part of the study (Walsham, 2006).

Historically, the vast majority of information systems research has been mostly quantitative in nature (Orlikowski & Baroudi, 1991). Of these quantitative study types, roughly half are utilizing surveys and another 25% of them are using experiments from the laboratory. Only about 3% of the 155 studies Orlikowski and Baroudi analyzed used a mixed method to get results, and this specific study has become the literature standard for those embarking on mixed methods research. There are many reasons why qualitative research, including personal interviews, participant observation, and document analysis, are good sources of information into how people tend to interact with information systems and within the confines of their daily jobs. There are a few criteria to help researchers decide whether qualitative approaches are appropriate for their study. The first of which is to understand how users feel about a system and what effect it has had

on their work experience. Another reason is to discover how the system has shaped the work environment and organizational attributes. It is also important to discover if there are any specific processes or events that cause specific outcomes in terms of business processes or financial outcomes. Qualitative methods are also useful when trying to eventually improve the usefulness of a system in an organization, instead of just studying how it currently exists in its environment. All these needs are reasons to provide at least a qualitative aspect alongside a quantitative approach to the research methodology (Kaplan & Maxwell, 2005).

Interview research, while useful, can also have many pitfalls and possibilities for error, specifically in information systems research which does not have a wealth of structured interview data (Myers & Newman, 2007). Some of the problems with interviewing come down to a lack of trust in the interviewer, the level of the subject being interviewed, ambiguous language, leading questions, as well as the Hawthorne effect. All these possible problem areas in survey research must be identified, explained, and accounted for in the conclusions after data has been collected and analyzed.

3.4. Research Questions & Guidelines

It's important to note that since the main goal of this study is to identify specific common characteristics of SMEs who have implemented PDM systems, there are no null or alternative hypotheses. Instead, because this is an exploratory study, the researcher will be looking for trends in the data in terms of shared characteristics according to responses. This would take the form of finding percentages of subjects responding to questions with similar responses. For a specific response to be considered "common" will depend largely on the sample size – at least 25 companies will need to take the survey for the results to be considered a representative sample of the population, which is standard for human-based research studies. The definition for "common" will also depend on the number of possible responses. A sample of 30 companies that answer a

question with 5 possible answers could result in no obvious answer being more frequently chosen over the others, and in this instance no commonality would be concluded. However, in that same situation, if over 40% of the respondents give the same answer, that could clearly be the most common response to the question, even though it is not the majority. Considering these possibilities for response levels, the researcher has set a cutoff of 35% or above of respondents reporting a specific answer to be considered “common” in such cases where all possible answers are equally low.

Moreover, simple percentage responses do not tell the whole story of how SMEs are experiencing PDM. Therefore, the researcher attempts to correlate different variables with each other to detect any relationships between specific responses that may give clues to real underlying explanations for the state of the data. To achieve this, the researcher utilized chi-square tests to determine the occurrence of one particular response to a variable in relation to another response in another variable. This approach has been used in similar studies on IT implementation when comparing two categorical variables (Yassine, Kim, Roemer, & Holweg, 2004). These chi square tests examine as many variable relationships as possible.

3.5. Methodology

The population in question is American small and medium manufacturing enterprises with fewer than 500 employees. They may or may not have considered implementing a PDMS, and might not have even heard of product lifecycle management as a process for designing, manufacturing, and managing products. Therefore, it is important to select a sample from this population that has experience with both PLM methodologies and PDM as a vehicle for PLM. After preliminary interviews were completed, questions for a multi-level survey emerged that separated companies that have PDM experience from those who do not. Companies with no experience were asked to respond to the survey, but they did not see any questions beyond the demographics questions about

customer/supplier relationships and the use of 2D/3D CAD. The prevailing idea is that small companies that have experience with these theories and their practice are good places to start to help other similar companies who have not yet considered PDM to manage data, do so in an efficient and successful way.

Because of the relative lack of previous literature examining manufacturing SMEs in the US, a short qualitative type interview was held with 4 different experts in PDM implementation and management in companies where it has become prevalent. Although these subject matter experts were not all employed by small companies using the definition for this study, they were asked what their relationships were with their suppliers who tended to be small companies, and how they dealt with the differences in PDM capability. The entirety of the interviews was voice recorded and transcribed by the researcher with all identifying information removed for participant anonymity. The goal of these interviews was to ask very general questions about their PDM experiences, focusing most on what has been unique to their situation and also what they feel other companies who are looking to implement a PDM system soon should know (Kropsu-Vehkaperä, Haapasalo, Harkonen, & Silvola, 2009). These questions have been asked in other studies related to PDM implementation, regardless of company size or nationality, and are therefore a good place to start asking questions from this smaller group (Wognum & Drongelen, 2005). From these short, semi-structured interviews, a list of quantitative survey questions was developed based on the answers by the experienced SME employees. The following questions were asked during these interviews:

- What kind of pressures do your customers exert on your organization in regards to your design software?
- What was the biggest hurdle to the successful use of PDMS in the design process?
- What has been the best & worst effects of PDMS in the company's design process?
- What has been the biggest effect of PDMS on your daily job duties?

- What is your overall impression of the PDMS and has it positively or negatively affected the company as a whole?

After the interview recordings were fully transcribed and stripped of identifying information, they were coded using grounded theory and open coding qualitative methods to extract the main idea threads which were then used to create survey questions that would best identify the important traits for SMEs contemplating or currently using PDM technologies. Coding was done using an open coding methodology to identify key concepts that were addressed during all interviews (Strauss & Corbin, 1998). Data collection for the quantitative survey was done online via Purdue's Qualtrics service. The questions asked on this survey can be seen in Appendix E.

Due to the nature of the data, the analysis includes discrete measures like averages and percentages of scores and frequency analyses. The large part of the analysis of quantitative data is the search for variable relationships and comparing and contrasting data between companies. This was accomplished using chi-square tests by comparing response levels between two independent variables, such as company size and PDM usage, for example. Once the chi-square value was found and compared against an alpha significance level of .05, the researcher can conclude if the relationship between the two variables is due to chance or is actually showing a significant relationship. The overall goal of this research was to confirm similar studies to a degree while at the same time exploring critical factors about PDM implementation that have not yet been explored, specifically in the United States. Therefore, a descriptive, survey-type of study was most advantageous to gain useful information from small manufacturers.

Due to the nature of these preliminary interviews and the subsequent survey, there is no real variable manipulation involved. However, there are a variety of variable relationships that were investigated, such as:

- Company size (number of employees, locations, etc)

- Customer/Supplier relationships
- Current levels of PDM activity
- Current experiences with PDM

With this survey-style, ex post facto study, there are threats to external validity that need to be acknowledged and controlled as much as possible. For example, because there is no formal experiment involved, threats to internal validity are minimized, however, threats to external validity are magnified (Sekaran, 2002). The generalizability of these results is somewhat limited. No matter what results come from the study, it is important to stress that the recommendations for SMEs who fall into the categories that this study covers will not be able to take those recommendations and implement them right away without thought and planning (Cohen, Manion, & Morrison, 2000). Basically, the final results may not be immediately applicable to a specific company, but will merely be guidelines for SMEs to follow when considering whether or not to implement PDM themselves.

Another external threat to validity is the representativeness of the sample to the population, and while this will be as carefully controlled for as possible, the researcher has little control over who will ultimately respond to the survey, and to what degree (Campbell & Stanley, 1963). This means that companies in a specific industry may have a larger response than other industries, or larger companies within the SME umbrella might respond less than smaller companies with more intimate management structures. Another threat that may have an increasingly larger threat is history (Tashakkori & Teddlie, 2003)– due to the current economic turmoil, it may be difficult to get a wide range of responses because smaller manufacturers are typically hardest hit by a recession, and their first priority may not be participating in a study on PDMS, because improving their data infrastructure is probably not currently their most critical way to survive and thus not their first concern.

3.6. Projected Timeline

January 2010 – Submit an IRB exemption form on the grounds that the survey will be completely anonymous, will not pose any more risk to the subjects than everyday life, and subjects may withdraw participation at any time during the study. At this point the IRB submission contained only the specific preliminary interview questions and was revised after the interviews were finished.

January 2010 – Pending approved IRB approval, collect contacts for SMEs who will participate in the quantitative survey. These contacts may come from mailing lists, professional organizations, university contacts. After IRB approval has been reached, contact PDM experts and conduct phone interviews to discover questions for internet survey.

February 15th, 2010 – Compile interview results, create survey questions, submit revised IRB document with completed survey questions

March 17th, 2010 - Send out the survey to all prospective companies and their contacts with a cover letter explaining the research study and asking for their participation within the next month and a half.

April 1st, 2010 – Cutoff date for the online survey. Companies that have not responded by this date will no longer have the opportunity to respond. Experts report that internet-based surveys typically take two weeks to complete, with a followup reminder email sent out one week after the initial survey was sent (Dillman, 2007). The target response rate is approximately 60 companies at a minimum.

April 2010 – Compile results from online survey

3.7. Chapter Summary

This chapter discussed the type of research to be conducted including preliminary interview questions, subsequent survey data, the methodology, and the proposed method for analyzing the data. A timeline was also detailed for the study.

CHAPTER 4. RESULTS

4.1. Introduction

As previously stated, much research has been done into the characteristics and practices of small and medium manufacturers in other countries besides the United States. However, there have not been any studies conducted within the United States relative to PDM and PLM usage and experiences specifically targeted at small manufacturers. Typically these smaller businesses are underrepresented in other surveys. Due to this lack of previous comprehensive survey data, it was necessary to first interview PDM experts to get their feedback on their own experiences with PDM and from this, identify important areas to include in a wider survey to small manufacturers, as well as what was not important to include. Once the interviews were transcribed and coded, several key areas of concern were identified as being critical and insightful to discover more about small manufacturers. These key areas were translated into questions, again based off interview results, and transformed into a comprehensive internet-based survey that was emailed to as many small and medium manufacturers as possible. From the results taken from that survey, chi-square tests were used to link different characteristics to each other in an effort to paint a picture of what the SME's experience of PDM has truly been like, and what their common characteristics are.

4.2. Qualitative Interviews

The qualitative interviews were performed over the course of a 3 week period in January and February 2010, and due to distance related issues, were all performed over the phone. Three of the four interviews took approximately 30

minutes to complete with the fourth interview lasting approximately 90 minutes, and stuck mostly to the questions that were predetermined, but since interviews were semi-structured, additional questions were sometimes asked, based on the direction of the answers at the time. The entire transcription of the interviews can be found in Appendix B. First, the participants for the interview portion of the study will be discussed, and then the actual content and methodology for how the interviews were completed. After this, the presentation of codes and explanation for how survey questions were generated from interview content will be detailed.

4.2.1. Participants

There were four participants who engaged in recorded phone interviews for this study. Because they were being asked questions about their employers and places of work, as well as the inner workings of their companies, they were promised near-complete anonymity for the purposes of this report.

Participant 1 was an expert in PDM for a major aerospace OEM specializing in military applications. He'd worked with data management, specifically configuration and change management, for about 15 years, and had a keen understanding of the overall process for managing data for his part of the company. He spoke volumes to the strengths and weaknesses he has perceived with modern PDM systems, as well as the way his organization tends to use and view it, and was able to give many different stories of specific issues or successes he's experienced just recently with his work in PDM.

Participant 2 was a project manager overseeing PDM implementation and management for a mid-sized aerospace OEM specializing in commercial applications. He had a lot of experience talking to different levels of his company about PDM and managing its updates and usage throughout the organization, and ensuring it runs smoothly for everyone involved. He added concise information about the organization's dealings with its suppliers which clarified how the end survey ended up classifying suppliers based on their relationships with their customers.

Participant 3 was an employee of a government institution for maintaining standards for technology. He had much to say based on his experience consulting with various government entities, particularly the military, on how to best implement and maintain PDM and PLM systems. He was very knowledgeable about different software capabilities and illuminated the vast cost savings he has observed in the field as companies properly implement PLM methodologies.

Participant 4 was a technical manager for a mid-sized engineering and manufacturing firm specializing in industrial equipment. His organization did engineering design as well as manufacturing for their customers, and likewise had many suppliers to juggle. The company is in the midst of implementing a PDM system and he has been overseeing it, so his input on the struggles that the organization has experienced trying to reach the goal of ubiquitous PDM implementation was very useful.

All four participants were contacted through email prior to interview taking place, and all were read their human research subject rights to remain anonymous and refuse to answer any question. However, they all graciously answered all questions and provided great feedback that helped direct the researcher on what to ask small manufacturers. Many of the points brought up had not been previously discussed in literature or found from other sources, so their input was invaluable.

4.2.2. Interview Questions

Interview questions were devised based on the existing literature about general small manufacturer characteristics and experiences. These questions were asked of interview participants, but were phrased slightly differently based on the participants' individual traits. They were intentionally worded with broad meanings to enable participants to answer freely and reduce the risk of the researcher influencing the answers.

The questions are as follows:

1. What kind of pressures do your customers exert on your organization in regards to your design software?
2. What was the biggest hurdle to the successful use of PDMS in the design process?
3. What have been the best & worst effects of PDMS in the company's design process?
4. What has been the biggest effect of PDMS on your daily job duties?
5. What is your overall impression of the PDMS and has it positively or negatively affected the company as a whole?

4.2.3. Conducting the Interviews

As previously stated, all interviews were over the phone and voice recorded. Three interviews utilized Google Voice's call recording capabilities ("Recording phone calls : Calls - Google Voice Help," n.d.). The fourth interview used Microsoft Windows' Sound Recorder software with a microphone held to the speakerphone of a regular phone ("Recording Audio," n.d.). The goal of this was to enable easy and secure storage of audio files digitally to be more easily played back later during transcription.

Interview participants were contacted via email to solicit their participation and agree upon a time in which the interview would take place. Each interview began with a recitation of participant rights as outlined by the Institutional Review Board's requirements for exempt human research. Both the contact and script documents can be found in Appendix A. After this short introduction, participants were asked the first question and allowed to answer accordingly. After they seemed to feel like they'd answered the first question, the researcher moved on to the next question, and so on. Depending on the participant, the interview sometimes took the form of a conversation, and others were more structured with fewer or no follow up questions based on the 5 preset questions.

Once each interview was completed, the researcher thanked the participant for their time and the phone call ended. Once all interviews were completed, transcription began to record the text of all the interviews.

4.2.4. Interview Transcription

Due to the relatively small amount of audio recorded (approximately four hours of audio), the researcher opted to transcribe the audio recordings manually to help ensure anonymity of the interview participants. This is due to the sensitive nature of some of the recordings in terms of identifiable information. Therefore, the researcher transcribed audio recordings by hand using audio playback software on a computer that slowed the recordings down to about 50 percent of their normal play speed to ensure accurate transcription simultaneously with audio playback.

During the transcription process, any identifiable information that participants disclosed was removed or reworded to remove the possibility of identification. The transcript was also cleaned up to omit speech stammering and redundant sentences on both the part of the participant and the interviewer. This was done in an effort to make qualitative coding go more smoothly and increase readability of the final transcripts.

After rough transcription for all interviews was completed, it was formatted to correctly show which text was spoken by the participant versus the researcher. A final pass through the transcript to ensure all identifying information such as product names or company terms had been removed.

4.2.5. Coding

The basic strategy for coding the transcribed interviews was to summarize general ideas that were being presented by the participants, and then organize and rank these concepts based on frequency, using the actual text from the transcripts, to then create basic concepts for which questions would be based.

This required approximately three to four runs through the transcript to generate codes, and then group them appropriately. What follows is an explanation of the major themes found from the coding process with some quotes that will help illuminate why codes were grouped in such a manner. All codes are listed in an organized manner in Appendix C.

4.2.5.1. Data Retrieval

Having the ability to easily query the database for information proved to be a major strength that all interview participants reported. They felt that the less time it took engineers to retrieve data, the more time they were spending doing real engineering work that contributed to the bottom line. It was also very apparent how much faster newer database systems were over older mainframe systems that were only accessible to a few people:

Once you start going down the road where you start treating the information as database objects, database information, getting information out of there is just phenomenally fast.

They also felt that using an organized digital environment decreased the amount of time spent having to write and fix queries as they were made.

Although a PDM system has a few disadvantages, they felt it was overall worth the fact that rework would be severely curtailed:

It'll also help us look at things quicker I think, and be able to do some similar practices from place to place rather than reinventing the wheel each time. It's brought an awareness to people to, that we're doing an awful lot of duplication that we really don't need to be doing.

4.2.5.2. Data Flow Beyond the Design

There were several different topics that arose from the coding process relative to how data flows beyond just preliminary design. One of them was the idea of single entry, which basically meant that companies are using PDM to enter data into the system only once, and then reusing it later on in the design

and production processes. All participants agreed that the power of data reuse had come to be a very important tool in their organizations:

Now it's more about propagating the data, linking the data, making sure all the data is formatted properly and usable downstream. Making sure it's available to everybody.

A few of the participants also spoke to how they had seen PDM reduce the level of work later on in the engineering process based on data reuse and availability, as well as preventing entry errors:

Just the reduction of errors – reentry of data causes a lot of errors. If we're able to use the data from one system to the next, if I can take it from the design system to the analysis system into the manufacturing system, I give it to my suppliers, I can validate if I do translate something, I can do a validation on that and certify that that's good translation. All this stuff just really starts paying off.

However, one participant in particular was sure to caution against the inherent mindset that PDM will automatically make design easier – he mentioned that despite the advances that have been made in these design systems, there is still a long way to go before they are effectively communicating with other similar yet necessary systems, such as MRP:

...with MRP in place handling the buying and productions and shipping schedules, a PDM system or a product lifecycle system doesn't work well with MRP.

4.2.5.3. Data Exchange with Customer, Supplier, and Other Sites

The issue of data exchange became an especially apparent theme throughout the interviews. Many of the interview participants were working for OEMs, but when asked about their data exchange with suppliers, they almost uniformly had a story where their organization struggled to effectively share data with a supplier, which many of the small companies this study focuses tend to be.

A major focus of the integration struggles that participants had experienced came from security problems. This tended to be a theme based on the fact that larger OEMs tend to have more sophisticated IT security systems

and experience constant problems trying to get their PDM systems to communicate through firewalls and other security mechanisms:

We had to come up with a whole new system that we had to hand write ourselves, that we don't use the ODS server, we just use the basic import/export capability, but we had to write our own queries, our own exports, we had to have our own SVLP transfer process, it's one of these new secure protocols. That goes through our firewall, and it's a server that's on the firewall, it's part of the firewall capability, then the customer we had to give him a program that automatically queries that server to see if there's a new package there, we had to set up the customer with his own software so that it's put on a cron job, and it runs at 3AM. Just to get automatic transfer of information between the customer and us, there was no out of the box capability because security said no.

We spent several hundreds of thousands of dollars getting this one supplier stood up.

Even after security issues, there are still process changes that need to take place to accommodate efficient data exchange. A major one was data formatting, which was broken up into several subcategories to adequately describe the concepts mentioned during the interviews.

4.2.5.3.1. Data Formatting for Exchange

Data exchange in these situations can take a variety of different formats, especially when it comes to communicating with entities external to the company's own systems. The first issue was system integration, because some of the participants mentioned that they asked their suppliers to integrate those systems with their own:

On the hardware supplier, i.e., we send data out and they send back aircraft hardware, we encourage the supply base to participate in our electronic data enterprise and give them a requirements specification for assets they need to acquire in order to do such. Those assets include CAD tools, and the requirements to keep their CAD tools in sync with our CAD tool for any given program.

This paradigm changed based on what type of relationship the OEM had with the supplier. Some suppliers supply primarily engineering design and do not

manufacture anything, while others do both engineering and manufacturing themselves, and many others only manufacture to the OEM's specifications. Because of these complex relationships, it is increasingly obvious that PDMs are not yet able to efficiently handle this level of sophistication. However, both OEMs and suppliers are doing what they can do accommodate each other:

Some of our larger customers, GE, GM, they send things in the format they want to send it in, and we find a way to make it work.

We have the processed part file, and then we put in the log file that is the log of the software that processed it. So we have a record of exactly what happened. And all that gets zipped up and put there. And now the supplier, it's his choice which format he wants to use.

Participants also mentioned that they've had to use trial and error to discover a method for exchanging PDM data externally as well as internally that works in most instances. Often they must be equipped to handle traditionally unusual peripheral data such as tooling information and format data a certain way up front, knowing that later on in the design process it will be easier to deal with in the different format:

Two, you have to put the information in a format that works downstream. So, sometimes you have to adapt formats and concepts and schemas that are being used downstream, upstream. An example for us has been our MRP system. The MRP system is a monster, it's huge. You're not gonna change it. Or at least you're not gonna change it anytime soon.

4.2.5.3.2. Data as a Deliverable

Several participants reported data as a deliverable as a new trend that is helping to drive the development and integrated use of PDM systems. Basically, they've seen an increase in requirements to deliver the data that was generated during the design of a product along with the product itself. Excluding small manufacturers who are effectively job shops and do no design themselves, this can potentially affect all segments of the industry, regardless of size or situation. In the past, there was nothing in the business contract to deal with data:

We went from one extreme which is, the customer lets us do whatever we want, they really don't care, at the end of the day we just have to give

them sometimes just lists of information. I mean sometimes it's just an image, they don't even care if it's in an ASCII, or a format that is something you can bring in Excel, and manipulate in a digital environment. It could just be a printout.

Which has now become a specific contract statement to follow exact specifications on the handling and delivery of digital design data and metadata:

Well, in the design data supplier use case, those elements are included in the contract with the design data supplier for engineering services up front. The applications, the procedures, and the refresh cycles are priced into the contract, those are contract deliverables.

4.2.5.4. General PDM Characteristics

There was much discussion, both positive and negative, from the participants, relative to out of the box functionality of PDM systems. This subject is particularly important for smaller companies that don't have the resources to heavily customize their PDM installations. There were several observations about the limitations of PDM out of the box, as well as how even well configured PDM systems in companies that are comfortable with their use still run into exceptions during data management that must be dealt with intelligently:

The OEM [software vendor] comes out and says, hey! This tool, or these features of the PDM, these features are little sub-tools. It's supposed to solve this problem. This is how it works. And you have to say "well that's one use, you have to keep in your mind, that's one use for that tool. That might solve another problem."

There are still a lot of problems, a lot of tribulations, gaps, IT problems, that you're just going like "how can that be?" And it goes back to the original thing, unless your actual product is going out the door, you don't get the same amount of attention.

Despite the difficulties experienced with PDM capability out of the box, participants identified a number of strengths, such as workflow management, centralized controlled storage, and the improvements upon older systems that tried to accomplish similar things:

There's the workflow, gotta admit the digital signatures are really nice... You don't have to walk around and ask people to sign stuff, so now you

have the workflows in the digital, but now we're getting more typical I think.

Maybe 10 years ago there were a lot of technical barriers, because the database systems were a little bit flaky, but those systems seem to be pretty robust now.

4.2.5.5. PDM Investment

PDM can become a very expensive proposition for any company, especially one that isn't prepared for the hurdles that may appear during implementation. All of the interview participants spoke about efforts to improving their design processes by implementing PDM, and trying to improve the PDM system itself. They also talked about investing money and time into changing software code versus changing processes to better adapt to what the PDM offers, and specific concerns their organization has experiences relative to these topics.

One participant in particular expressed frustration at the lack of visibility of the PDM system and all the maintenance it needs because it is a cost center and it is not easily monetized for a larger organization:

And like I said before, this is the back room stuff, it's not the value added stuff. It's not what the customer's paying for, it's not what has all the attention. The attention is on, what's the most efficient way I can produce that product and get it out the factory door because every time it goes out the factory door, someone puts money in my hand... That's where all the efficiency is. The back office operation doesn't get the attention, and that's one of the things I find happens all the time is, the PDM is not considered the value-added element in a product oriented company.

He felt this tended to cultivate an environment where the software tool should be forced to comply with current business practices when it would have been much less costly to simply change the business processes outside the PDM to conform to that which the PDM was easily capable:

I don't want to spend the money, and I don't want to maintain the custom code. That's not the value stream. The customer doesn't care, a lot of

times, exactly what your business process is, all they want is the product. So you have to look at what the OEM's PDM software come out and go "Okay, they gave me this, did they give me a solution?" Is it a viable solution, regardless of my processes. And if the answer's yes, you have to really ask yourself, "What's stopping me, from changing my processes to adapt to the tool?" And, it's also very anti-cultural. We've had a lot of top down, the managers saying, "Processes first, tools second."

Because of these attitudes in his organization, he has felt like assigning a monetary value to the PDM system has been impossible. A participant from a much smaller company expressed a different sentiment:

We measure everything in hard dollars and budgets. Everything comes down to operational expense... That's why it's got to be budgeted up front at the beginning of the project as part of a implementation project and not bolted on afterwards. We track everything in hard dollars. At the end of the day everything has its marginal contributions to earnings, and improvements in margins is tracked. That's the leading indicator.

Along with the ability to more easily monetize the PDM system, small companies who are simultaneously formally defining design processes while implementing their PDM system have had lot more luck because they are addressing many different changes at once, while avoiding having to customize code for the PDM system to work:

There are obviously workflows, you can't make parts before you do the drawings, but often times we try to react so quickly that we try to things simultaneously that just have to be done in serial, then you get in trouble. By making it formal, which is what PDM is going to enforce, it will be a frustration for some people to try to push stuff through at breakneck speed but it will also keep us from making those mistakes that, once it is there and it isn't what the customer wanted, we start over. Where, with some sort of semi locked in formal process control or workflow, we won't miss those things as often.

To help diffuse some of the cost and hassle, some companies try to ensure they are using software systems created by the same vendor, because they tend to have fewer integration problems and licensing tends to cost less. However, not all software vendors provide a complete suite of tools that handle CAD, analysis, PDM, and other manufacturing activities, and then companies are

more willing to invest in different software suites to attain the mix of functionality they are looking for.

4.2.5.6. People and PDM Interaction

When it comes to discussing the experiences the interview participants have had regarding how people in their organizations interact with the PDM, there was no shortage of comments. Their observations covered a variety of different topics such as concurrent engineering and the organizational change brought about by implementing and using a PDM system. One participant in particular talked about his daily interactions with coworkers and how they treated him based on his involvement with the PDM system:

Because this PLM stuff touches everybody's job, in some fashion throughout the whole organization, the folks that do the implementation become the face of the project, for all the good and/or bad. So the perception from the users can be very bad but the perception from the management can be very good, vice versa, perception from the users can be good and the perceptions of the managers can be bad. In theory it all works out and everybody has a net benefit.

Participants also talked about how the PDM and PLM systems they've come to work on in their companies is usually managed by a group with ties to both traditional IT as well as engineering, but neither of them exclusively. Often, it's managed by its own group entirely. This has presented problems such as security and process-related issues, but participants felt it was the best situation given the unique characteristics of the PDM system.

Another topic that came up frequently relative to how people interact with the PDM system was expectations of how the system should work. All participants agreed that the PDM system has become an integral part of the design engineer's job:

They're querying the database and spending more time in there than they used to. You ask the design engineers, what their differences have been, they'll say they're spending a lot more time working in the PDM.

Due to the increasing rate at which design engineers are becoming dependent on PDM systems, they're also forming opinions on its usefulness and making judgments on how well it is meeting their original expectations:

Engineers are very creative, freewheeling, energetic, enthusiastic individuals that don't necessarily like constraints. Putting structure to the data that they're generated through the use a PDM tool represents a constraint, although financially powerful, is not initially well received by the engineering staff.

Managing expectations is very difficult. Setting expectations and managing scope is very difficult.

. It has caused some pain for people in opening up the old stuff [engineering/manufacturing data] that's not where it was before and they have to go find it.

Most participants also mentioned that despite the added restrictions a PDM system imposes on engineers, it saves time over the long run because of those added restrictions and rigor.

One participant in particular spoke about the future of engineering and what engineers should be learning to help them better understand and work with the PDM systems that have become so pervasive to their job duties:

At the end of the day, an engineer retrieves information, processes the information, and then stores the information. That's what an engineer does. He doesn't go out and build anything. He is just processing information. Retrieve information, reformat the information to obtain more knowledge, to add knowledge, and then put the information and hopefully knowledge back into a system.

It does, the schools have to understand, at the end of the day, when the engineer comes out in industry, everything he's doing, retrieving information, processing information, storing the information. Well two of those are in a database. You've got to understand the basics.

As PDM becomes increasingly ubiquitous across an industry, this participant had the hope that more new engineering graduates would have experience working from a database than he had when he originally graduated.

4.2.5.7. Managing and Measuring PDM

As previously stated, participants made comments relative to the space in which PDM typically occupies within an organization – IT vs. Engineering. One participant stated that in his company, it had created a whole new career path for those interested because PDM has such deep roots in both worlds. He felt that although other systems, such as ERP, could fail outside of the IT organization, PDM was not prone to the same kind of weakness, but emphasized that if PDM was only managed by either IT or engineering departments, it may be less of a success.

Other participants also talked about the budgeting concerns associated with PDM and its complexities – especially a system managed by two different areas of the company. They felt it was difficult to measure the exact effect the PDM had on each product made by their organizations, but that extensive planning beforehand and being honest about its strengths, weaknesses, and general capabilities, helped ensure the PDM system succeeded within the company. They are using it to ensure quality control and help speed up engineering times, which in turn reduces costs.

4.2.5.8. Narrowing Down Codes

Out of approximately 20,000 words that were generated from the qualitative interviews with four participants, about 200 codes were produced. These 200 codes were then combined from all participants and categorized according to subject and subtopics. The subtopics were then ranked based on numbers of codes per subtopics. Some concepts were more obvious than others; data exchange, PDM characteristics, and interaction with people stood out as the concepts that were most mentioned during the interviews. However, many of the points brought up by participants were relatively new ideas about how PDM should be approached and what is most important to those who are working with it every day. These concepts were then worked into questions that needed to remain broad enough to be understood by a large variety of small businesses,

but ensure that they were hitting on the concepts that came from the coding process in an efficient way.

4.2.6. Survey Question Development

The initial subset of survey questions were meant to form a framework for what characteristics that small manufacturer had. Questions such as number of employees, industry, and level of digital design were meant to give background for each company and give statistics on the true characteristics of the sample responding to the survey.

4.2.6.1. Questions For All Survey Participants

Based on the responses from the interviews, the researcher realized that one of the key ways small manufacturers and engineering firms could be grouped was by their relationships with their customers and suppliers. Because each interview participant had a different type of relationship with their suppliers, sometimes having suppliers that only provided engineering itself, or engineered manufactured parts, or just in a job shop type role, the researcher felt it was important to get that kind of background data from small manufacturers because it could have an effect on whether they'd implemented a PDM-like system, and to what extent they used it. Therefore, questions were asked in the preliminary background section of the survey relative to whether the company was an OEM, a supplier, or both. Based on their response, they were asked whether they supply to or purchase parts from one or many other organizations, and what they tended to supply or buy. Finally, the survey taker was asked whether or not their company had a system set up specifically for handling engineering design data. If they reported that their company did not, they were automatically taken to the end of the survey and thanked for their time. If they answered yes, that they did have an engineering data system of some sort, they continued on to the next part of the survey. This was done mostly because it was quite plausible many small

companies don't have this system, and there may have been a connection between their other characteristics and the lack of a PDM system that could potentially provide valuable information.

4.2.6.2. Questions For Those With Engineering Data Systems

The decision was made throughout the survey to generally omit the term "product data management" from the questions, and instead use the term "engineering design system." This is due to the fact that product lifecycle management is a relatively new term and many smaller businesses may not be acquainted with the expression (Day, 2002). It was also possible small manufacturers have a system that does many of the functions of a traditional enterprise PDM system but may have a different name for their system, thus the most generic term was used to ensure survey participants wouldn't self select out of the survey due to a confusion in terminology. The issue of terminology appears later in this thesis as a consideration for future research.

Questions were also added to give a more accurate portrayal of the expertise of the survey taker by asking what their level of involvement was with the data management system. While users who responded that they were hardly involved or completely uninvolved were not disregarded, the question was asked to measure how reliable the answers relative to PDM usage were.

Other questions were based on the broader themes that were drawing from the qualitative interviews, such as methodologies for using the PDM system, workflow usage, opinions on how the PDM has affected the design process, and investment characteristics, which according to the review of literature, could be a possible variable that sets small manufacturers apart from larger OEMs. Another major theme that emerged which generated a few different questions was the level of system integration between both the small manufacturer and their customers/suppliers, as well as within their own organizations.

4.3. Quantitative Survey

Once questions were generated based on the codification and interpretation of the interview results, they were compiled into a survey that were to be delivered over the internet to as many small manufacturers as possible.

4.3.1. Survey Question Validation & Approval

Before the survey could be sent to prospective participants, the questions were first validated by a PDM expert who works for a larger aerospace OEM. He reviewed the questions before they were submitted for Institutional Review Board approval to ensure they indeed would provide a good picture of how a company may be using PDM in their engineering design process, and gave good ideas on ways to label Likert scale responses in a manner that were more understandable by providing labels for each of the five possible scaled responses. His approval was sought as a secondary way of ensuring validity of survey questions besides just from qualitative coding.

After the survey was reviewed and approved by this expert, it was sent to IRB in the form of a revision to the original submission that initially had only covered the qualitative interview portion of the study. Approval of the complete survey, including contact emails and vehicles, was given approximately one and a half weeks after submission, and the survey was sent upon IRB approval.

4.3.2. Survey Participant Collection

Due to time constraints, participant collection came from a primary source, with a few outliers. A few contacts were found on the internet through small manufacturing organizations that listed members and contact information on their websites. The vast majority of participant contact information was collected from a database composed of manufacturing companies based in Indiana, and filtered for employee numbers under 500 (*Indiana Manufacturers Database*, 2009). Companies that met this criterion then had their email addresses added to a

master list of possible survey participants. This resulted in approximately 2200 different contact email addresses for a variety of different sized manufacturers, mostly based in Indiana. About half of the email addresses were a general “information” or “sales” address that could be directed to anyone at the company. The other half comprised of what appeared to be actual personal email addresses that would go to one specific person.

4.3.3. Survey Vehicle

As previously mentioned, the survey was conducted online via Purdue’s purchased Qualtrics survey system. This software is capable of managing several surveys, panels of prospective survey participants, as well as simple results display and analysis. It also enabled the researcher to efficiently send out solicitation emails to the panel of survey participants and keep track of who responded and to what extent.

A feature offered by Qualtrics and utilized in this survey was the ability to selectively show and hide predefined questions from a survey taker based on their previous answers. Using this ability, the researcher was able to tailor the survey and ask more targeted questions that were applicable to each survey taker, such as asking for further details if they responded to a question in a particular way. Due to this capability, the results for survey questions are more likely to be accurate than if each survey taker saw all questions, regardless of whether they were applicable or not.

4.3.4. Survey Data Collection

Once the survey had been fully approved by the IRB, and created and tested within Qualtrics to ensure correct function, the initial contact email was sent out to the 2200 survey mailing list. Approximately 10 emails either failed or bounced back citing email filters or out of office replies. Each contact email contained an individualized link to the survey that enabled participants to forward

on the email to others to use the same email link. As each survey response was completed, an email was sent to the researcher to notify that a survey had been completed. The response was also stored along with previous response data. Responders who left the survey without reaching the completion screen were given 48 hours to return to finish the survey before their results were closed and added to the general repository of data.

The majority of survey responses came in the first 2 days of the survey being opened. A few more trickled in during the following days, but by approximately a week after the survey being first sent out, there were about 60 completed responses. According to research in this field, Wednesday mornings are the most lucrative time to send out surveys, so the reminder email was sent to email addresses that had not yet responded to the survey on a Wednesday morning (Faught, Whitten, & Green Jr., 2004). This resulted in an additional 40 completed responses within the next 6 days, for a total of 100 completed responses and an additional 40 incomplete responses. At this point, two weeks after the initial survey email, the survey remained open but data was harvested from the response set and used for analysis for the purposes of this study. This two week period has been typically recognized as a standard time period for internet surveys to receive an adequate number of responses to represent a statistically sound sample (Dillman, 2007).

4.3.5. Survey Data Statistical Analysis

The survey data was exported from the Qualtrics system into the statistical package SPSS, where it was analyzed using frequency and chi-square methods, both designed for categorical, or nominal, data. This statistical software generated frequency tables and charts for all variables. It also generated chi-square calculations for the interactions between different variables. Chi-square methodology is the most commonly used statistical measure for comparing groups of categorical data to determine whether they have a relationship or not (Agresti, 2007). This is especially useful when categorical data is of a binary

nature, as in a question has only 2 different answers, but as possible answers are added to each question, cell counts for each possible combination of question answers must stay high for the statistics to continue to be completely credible. This means that a higher sample size is needed.

4.3.6. Presentation of the Data

Due to the exploratory nature of this study, the data collected for the survey is meant to show relationships between variables as a way of suggesting that small manufacturers who have implemented PDM-like systems have common characteristics, and to examine what those characteristics are. This data has been cross-tabulated and chi-square tested to determine correlations between categorical variables, using a combination of statistical packages.

4.3.6.1. General Characteristics of Entire Sample

What follows is a breakdown by question of the frequencies and correlations for the entire sample, regardless of whether they were using a PDM system or not. It is important to remember here that survey respondents were able to skip any question they wished to, and stop at any time. As a result, the total number of respondents tends to change for each question. Because of this, the total number for each specific question is reported in the caption for each figure.

4.3.6.1.1. Industry Characteristics

The majority of the small businesses in this sample are working in the industrial equipment industry, see *Figure 4.1*. This title includes companies in construction manufacturing, HVAC, and other industrial applications. The next largest group labeled themselves as “other” with a variety of different industries cited such as “manufacturing,” general machining, metalworking, and agricultural

products. The next largest groups were in the automotive and consumer products industries.

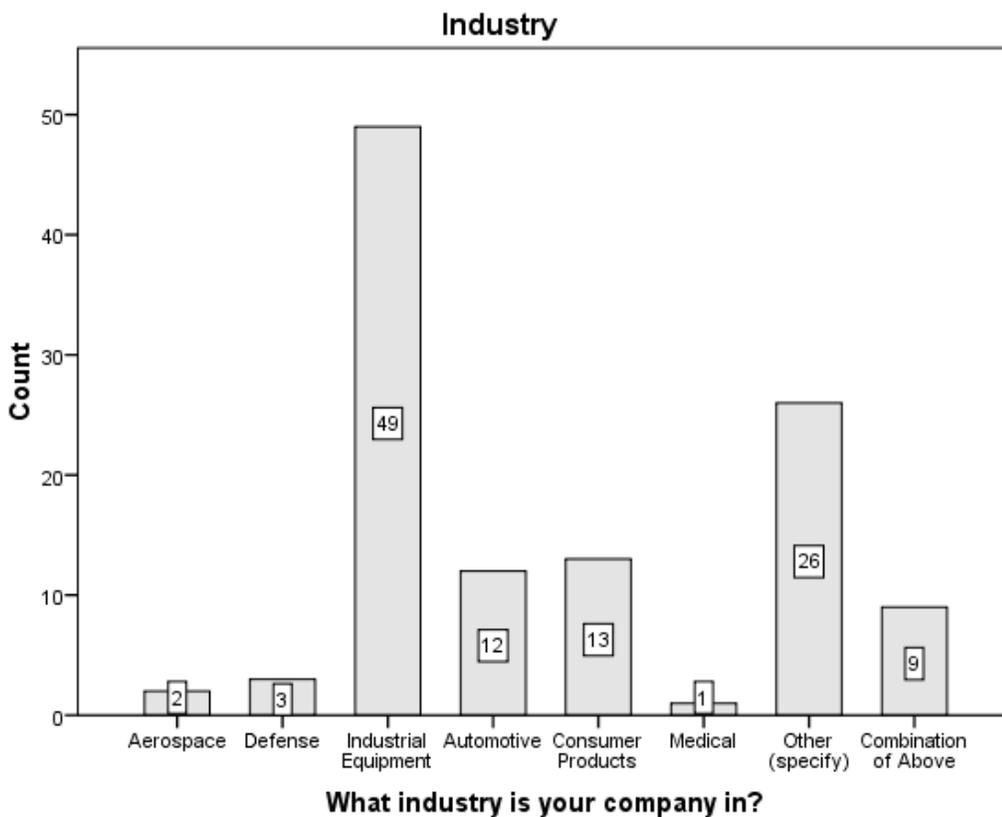


Figure 4.1 Industry Makeup, n = 115

4.3.6.1.2. Employee Counts

The vast majority of the respondents to the survey reported their company's employment numbers as being under 50 employees, see *Figure 4.2*. There were 11 respondents that reported having employee counts over 500, and the data presented in this section is the only one that includes companies reporting as having over 500 employees. All previous and following data has these respondents removed from the pool of responses.

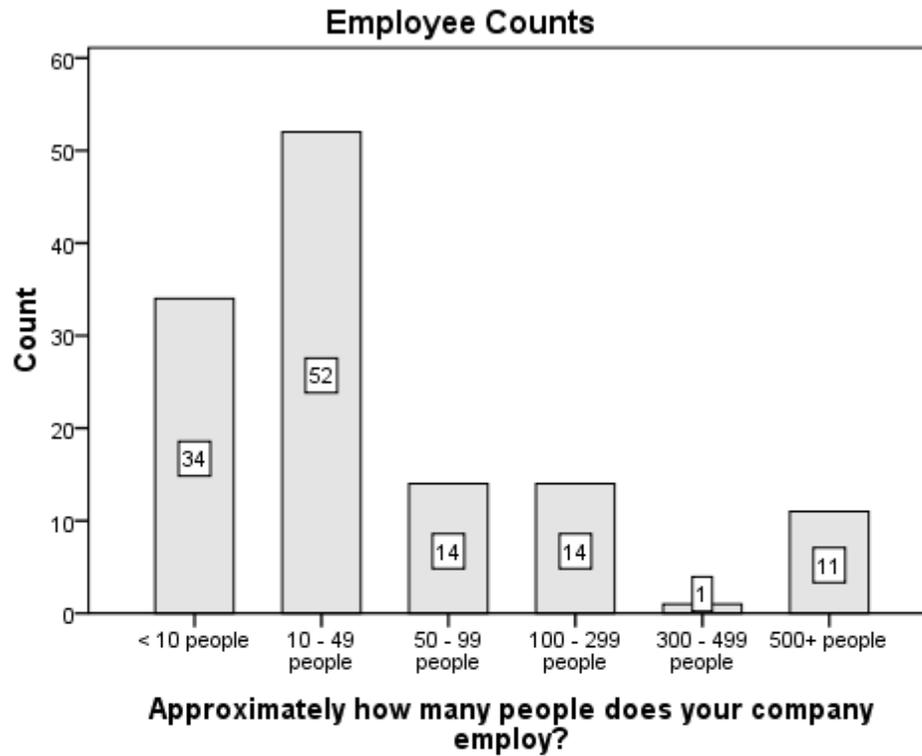


Figure 4.2 Employee Counts, n = 126

4.3.6.1.3. Design Locations

Most respondents reported doing engineering design at only one location, which is probably typical of small manufacturing businesses, see *Figure 4.3*.

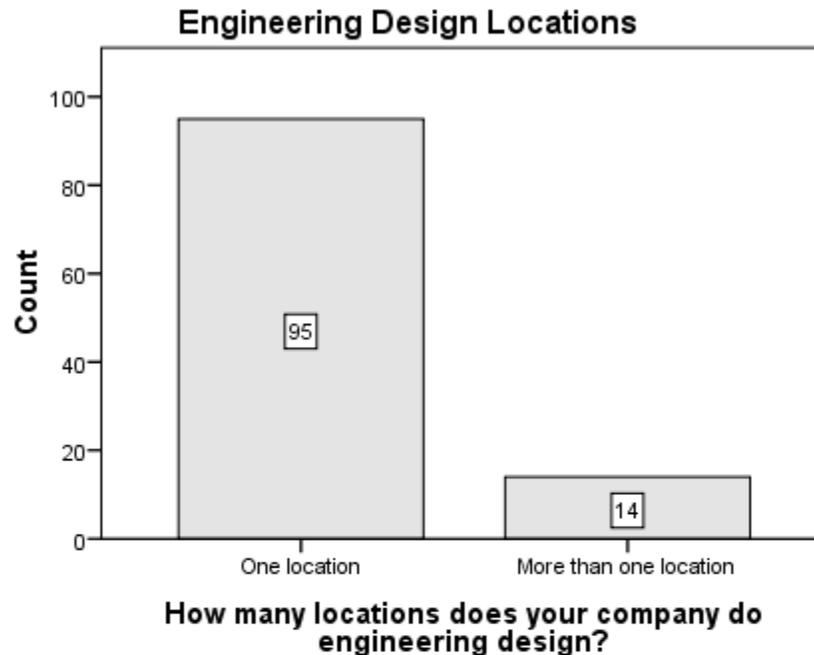


Figure 4.3 Engineering Design Locations, n = 109

4.3.6.1.4. Customer/Supplier Relationships

This section details multiple questions that asked about the type of business the respondent typically does. The first question, whether they were an OEM, supplier, or both, dictated the following questions each respondent saw. If users reported only being an OEM, they were only asked questions relevant to what types of parts and data they typically bought, and whether it was from only one, or multiple suppliers. Likewise, suppliers were asked similar questions about to whom they supplied. Respondents reporting that their companies acted in both OEM and supplier capacities were asked both sets of questions relevant to OEMs and suppliers.

The respondents were relatively evenly split up between being OEMs, suppliers, or both, although more tended to be suppliers, see Table 4.1. However, regardless of their relationship with customers and suppliers, they almost uniformly are working with multiple entities within each relationship, see Table 4.2 and Table 4.3. The majority of the respondents who reported as being

in an OEM role reported buying parts that were designed and manufactured by someone else, while those in a supplier role tended to both design and manufacture their products themselves, see Table 4.4 and Table 4.5. Some answers in which users reported an “other” response typically came from those who identified as OEMs who do not buy parts from other companies or felt that standard parts were not included in the question about their suppliers. Likewise, a few respondents who stated they work for companies that supply to others felt their products didn’t fall under the categories of “supply” due to their nature such as chemicals and part repair.

During the course of the survey, the researcher received more than a few emails explaining from prospective respondents that spoke of the fact that their company did not do “engineering work” at their site and therefore were not the target audience for the survey. The researcher had to reply to each of these companies and explain that the survey indeed needed their input as well, and that job shop type manufacturers need to handle data they’re receiving from their customers, and this succeeded in producing a few more survey responses than otherwise would have been.

Table 4.1 *Is your company an original equipment manufacturer (OEM), supplier only, or both supplier and OEM?*

Company Status	Frequency	Valid Percent
Original Equipment Manufacturer	28	25.2
Supplier Only	45	40.5
Both OEM and Supplier	38	34.2
Total	111	100.0

Table 4.2 *If OEM, do you buy parts from one supplier or many?*

# of Suppliers	Frequency	Valid Percent
Many suppliers	60	100.0
One supplier	0	0.0
Total	60	100.0

Table 4.3 *If supplier, do you supply to one OEM or many?*

# of Customers	Frequency	Valid Percent
One OEM	4	6.1
Many OEMs	62	93.9
Total	66	100.0

Table 4.4 *As an OEM, what do you buy?*

	Possible Relationships			
	Engineering design only (you pay someone to design the part but make it yourself)	Manufactured parts designed by someone else (you buy parts that were designed and manufactured by someone else)	Manufactured parts only (you design the part, but pay someone else to make it)	Some other situation (please explain)
OEM role	9	28	17	25

Table 4.5 *As a supplier, what do you supply?*

	Possible Relationships			
	Engineering design only (you don't make the part, only design it and give the design to OEM to make)	Designed and manufactured parts (you design the part and manufacture it yourself, then sell it)	Manufactured parts only (customer gives you design, and you make the part for them)?	Some other situation (please explain)
Supplier role	5	44	36	13

4.3.6.1.5. Engineering Design Formats

In general there was no significant difference in numbers of companies using 3D vs. 2D tools, see Table 4.6. This question was designed to allow users to pick more than one if both applied, but most actually chose one or the other, not both. Those who specified “other” typically cited using printed circuit board software or using drawings only instead of a digital format to define their designs.

Table 4.6 *What format does your company typically use to define engineering design?*

Tool	Frequency
3D CAD tools	52
2D CAD and drawing tools	54
Other (specify)	16

4.3.6.1.6. Existence of Digital Engineering Design System

The final question targeted at the entire sample of survey respondents also caused the sample to be split into two specific groups: companies that have a digital design system of some sort, and those that do not, see Table 4.7. Respondents answering this question with a “no” were taken to the end of the survey and thanked for their time, since the subsequent questions would all be about a system they did not have. By avoiding their input on the latter questions, the risk of contamination of data by misunderstanding of the concepts or frustration was reduced. The following parts of the study rely on the users’ response to this question, and therefore only respondents who answered “yes” to this question were included in the following portion of the survey.

Table 4.7 *Does your company have a digital system set up to handle engineering design data specifically?*

Design System?	Frequency	Valid Percent
Yes	42	43.3
No	55	56.7
Totals	97	100.0

4.3.6.2. General Characteristics of Companies Utilizing Design Systems

What follows is a description of the frequency results related to each question on the different aspects of PDM usage in small manufacturers that were addressed in this study.

4.3.6.2.1. Involvement in Engineering Design System

The first question asked of people who reported having a design system in their company, was to see how involved they were with the system, see *Figure 4.4*. This was asked in an effort to ensure that those who are answering questions about their company's systems are actually credible in their answers. The results show that the majority of respondents to this part of the survey were indeed knowledgeable about the system in question and therefore the answers that follow can be relied upon as being accurate.

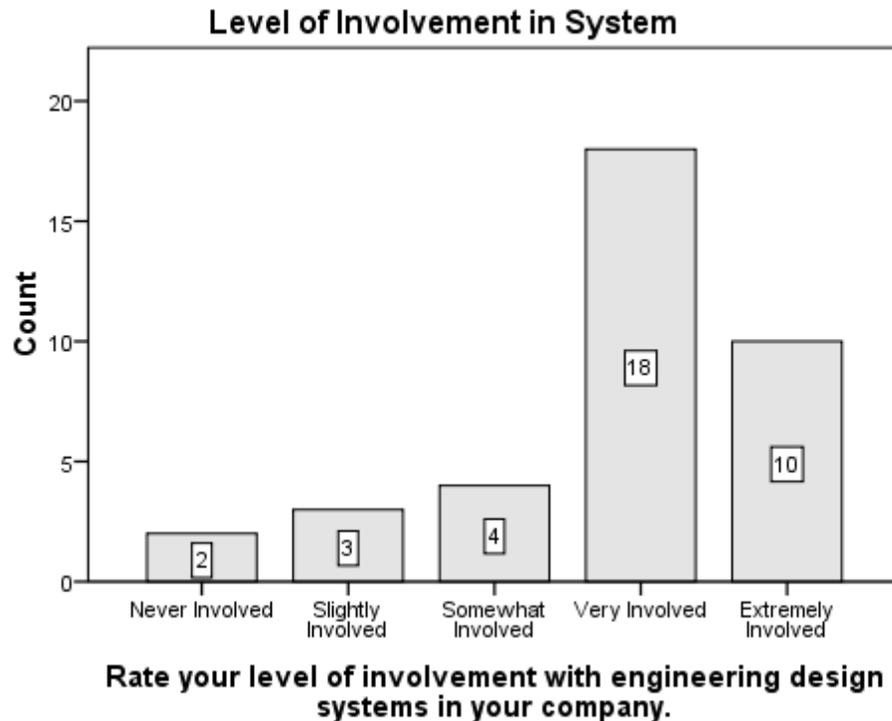


Figure 4.4 Level of Involvement, n = 37

4.3.6.2.2. Areas of Usage for the Engineering Design System

Another important piece of information to find out was the general areas of data management in which these small manufacturers were using their engineering design systems, see Table 4.8. This was especially important given the variety in types of businesses and customer/supplier relationships that are represented in a sample of small businesses. This question had a multiple choice option, because companies could potentially use the same system for different areas of their business. Most respondents reported using their design systems to manage manufacturing information such as tooling, schedules, and other such data. Product structure management and general data repositories were other widely used elements of engineering design systems.

Table 4.8 *Which general areas of engineering design do you use your system for?*

Area	Frequency
General repository for data that is controlled	19
Versioning and access control (Check in & Check out)	9
Product structure management (Bills of materials)	19
Engineering Change Management	16
Configuration management	13
Manufacturing information management	25
Other (specify)	3

4.3.6.2.3. Timing of Data Entry

Another topic that came up during the qualitative interviews was the timing at which engineering data was entered into the system. Depending on company culture and how the system was viewed, it could be used as an integral tool throughout the design process, or a simple repository for legacy data while most design activities happen outside the system. Because of this, and the history of small manufacturers, a question was posed about when data entry typically takes place, see *Figure 4.5*. In general the respondents reported trying to enter as much data as possible at the beginning of the design process, but there was still a handful that were using their system for archival purposes.

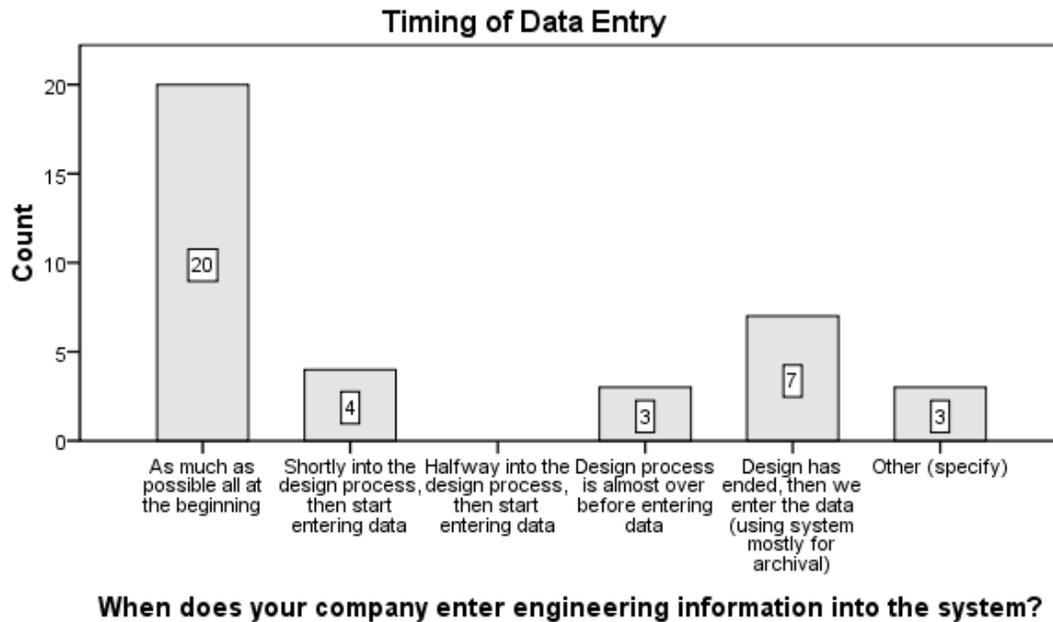


Figure 4.5 Timing of Data Entry, n = 37

4.3.6.2.4. Workflow Usage

The use of automated workflows was mentioned in the interviews both by those from large companies as well as smaller ones, as being one of the biggest strength of PDM systems in particular. Therefore, it became a question for small manufacturers to see if they are utilizing this functionality in their own systems and to what extent, see *Figure 4.6*. Although many of the small manufacturers report not using workflows at all, the majority of the responses are reporting that they are using workflows to different degrees.

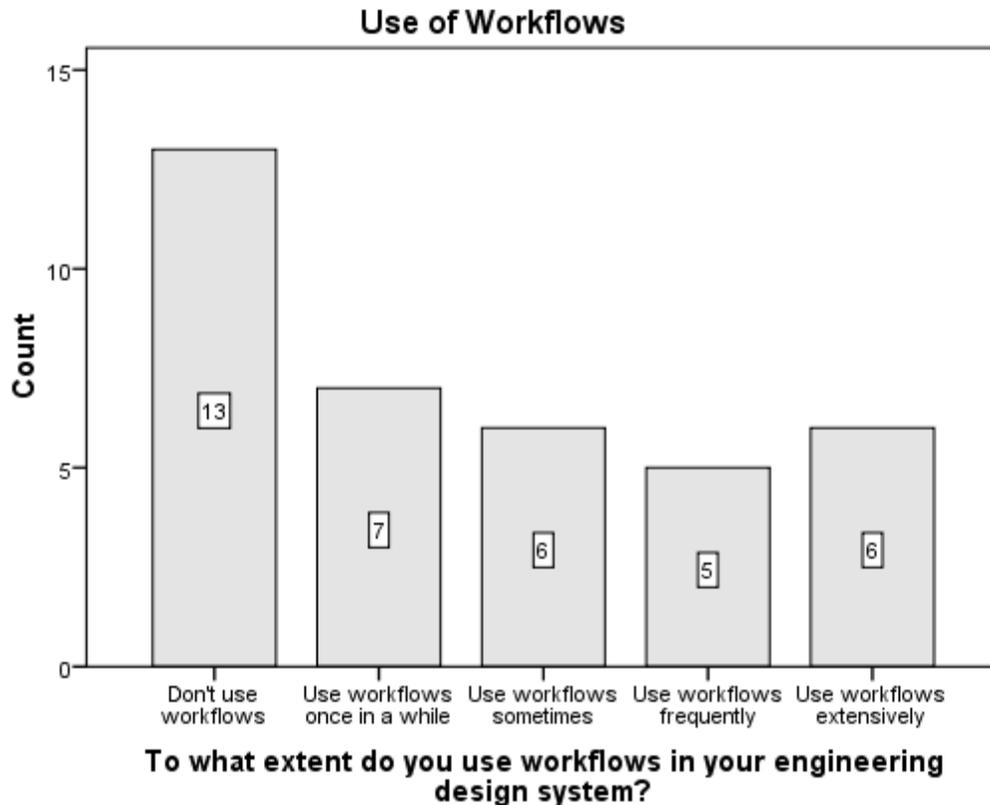


Figure 4.6 Use of Workflows, n = 37

4.3.6.2.5. Time Effect on Design Tasks and Finding Information

The change in the amount of time needed to complete a design task such as a design change, new part or configuration was an important point made during the qualitative interviews and was also revealed during the coding process. Therefore, it became important to discover whether small manufacturers were experiencing the same effects in time to complete a design task, see *Figure 4.7*. They seemed to be evenly split between a decrease in task time and no change to even a slight increase in time needed to perform these tasks. However, no respondent felt their engineering design system made design tasks much slower.

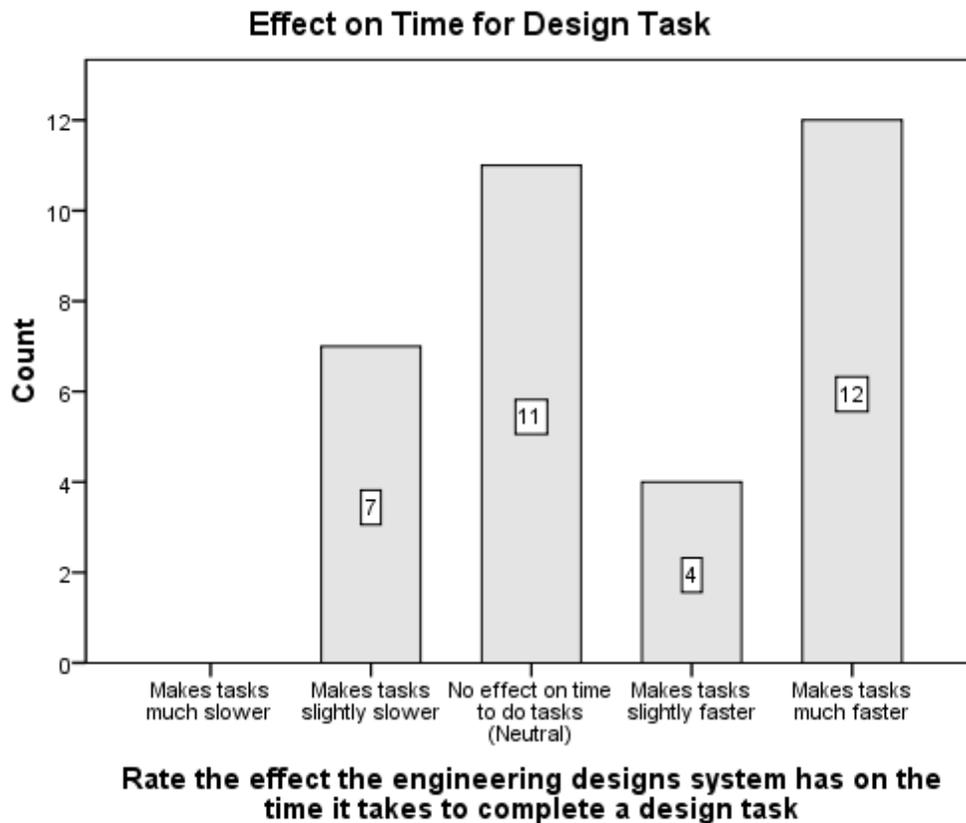


Figure 4.7 Effect on Time for Design Task, n = 34

The ability to query the design system to find information quickly was iterated as being a major strength of engineering design and PDM systems. Therefore, it was important to see if smaller manufacturers, with potentially less data, are still reaping these same benefits from their systems, see *Figure 4.8*. They appear to feel that finding information is faster in general, with only about a third of respondents reporting no effect or a slower time than before the system was implemented.

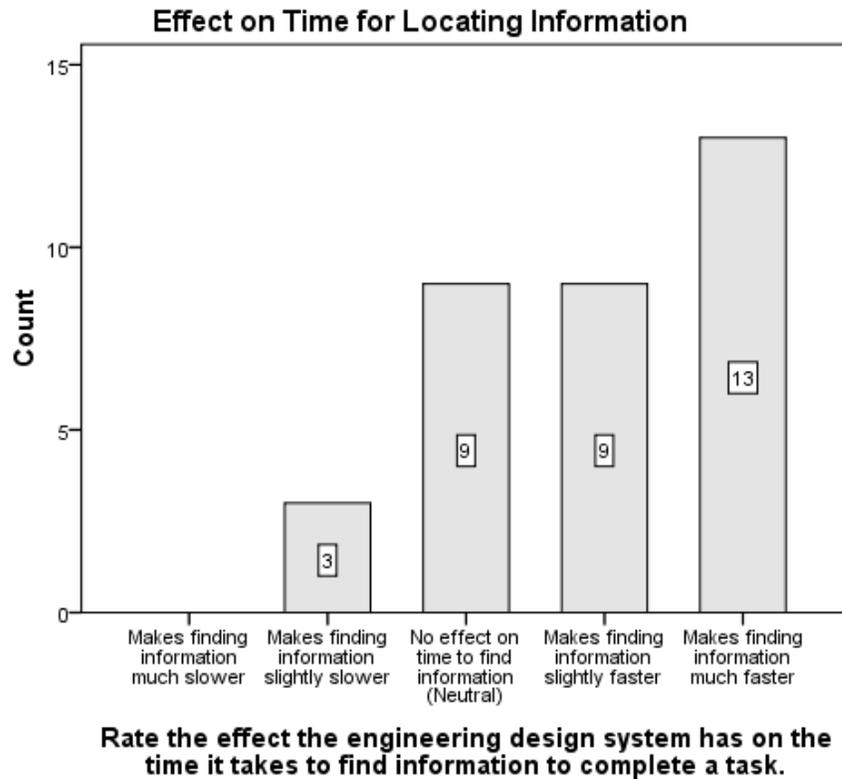


Figure 4.8 Effect on Time for Locating Information, n = 34

4.3.6.2.6. Data Sharing Beyond Engineering

One of the greatest strengths of PDM systems, which was reinforced during the interviews, was the ability to reuse engineering data in other parts of the business. This is especially crucial for small companies that may have limited resources, who can stand to benefit the most from data reuse in other systems relative to manufacturing such as purchasing and order tracking. In general, two thirds of the respondents reported that their systems enable flow of engineering data into other parts of the business, see *Figure 4.9*.

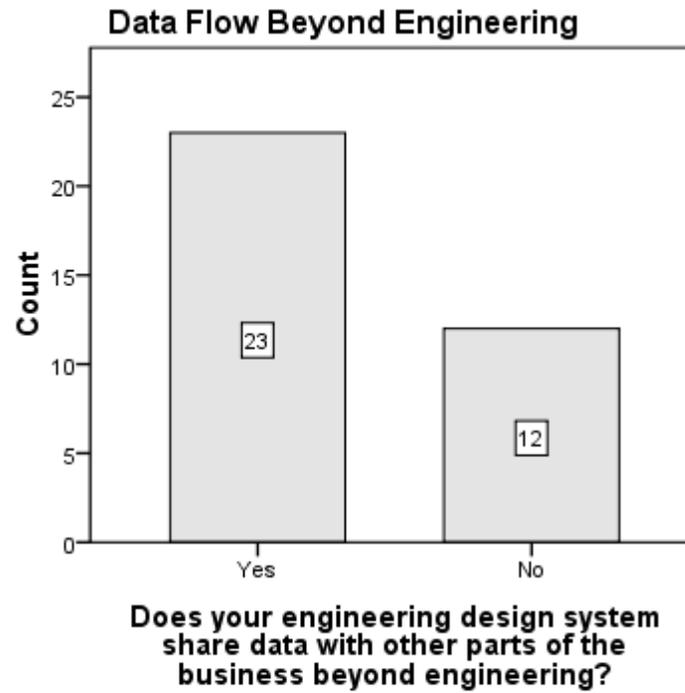


Figure 4.9 Data Flow Beyond Engineering, n = 34

Users who reported that their engineering design systems did share data with other parts of their business generally share it with manufacturing and purchasing, see Table 4.9.

Table 4.9 *Which parts of the business share data with the engineering design system?*

Business Area	Count
Ordering	13
Purchasing	19
Manufacturing	20
Finance	10
Human Resources	1
Other (specify)	3

4.3.6.2.7. Data Sharing Beyond the Company

Another major theme that resulted from the coding process was the sharing of data between companies, whatever their relationship is. Due to the immensity of this subject and its potential effect on small manufacturers in particular, several questions were dedicated to the topic. Variables such as frequency of contact, method of data exchange, and file formats used were explored. Generally, respondents report that their companies are exchanging data with outside entities, be they supplier or customer, on a daily, if not weekly basis, see *Figure 4.10*. Much of this data may be manufacturing information and ordering, but it's important to note that they are indeed communicating frequently. However, this communication tends to be manual for the majority of respondent companies, see *Figure 4.11*. Those companies that are doing automated data exchange are across the board on the level of automation of data exchange they have implemented in their systems, see *Figure 4.12*. However, despite the manual process most companies are using to exchange data with their suppliers and customers, much of it is using neutral file formats, instead of native file formats, *Figure 4.13*. This is an important distinction for companies using 3D formats especially.

When asked what the nature of their data exchange was, a variety of interesting answers resulted. Many companies are communicating mostly approvals of final designs and materials information. A few are communicating advanced digital data such as finite element analysis and fluid dynamics

information, while still others use only drawings to communicate design. Most communication occurs over email or through physical mail.

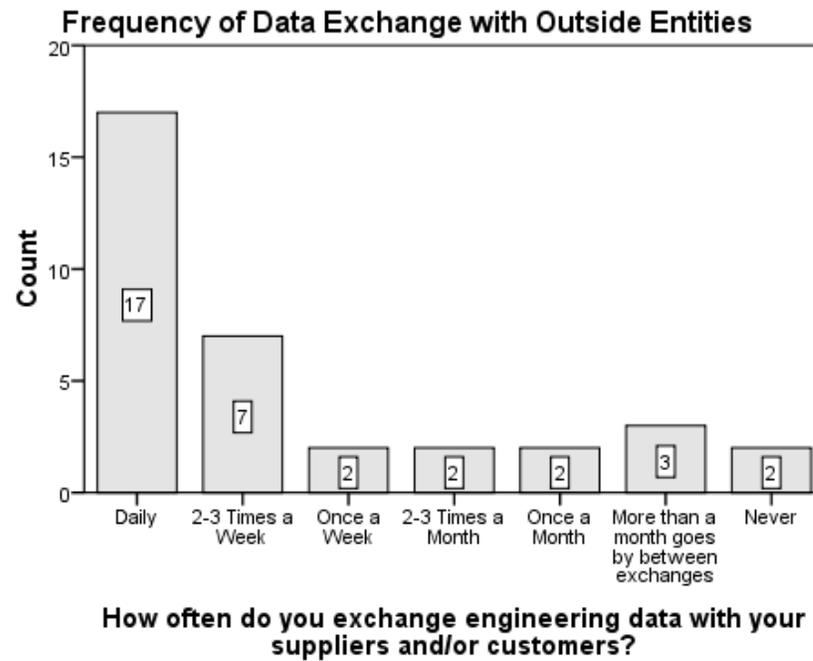


Figure 4.10 Frequency of Data Exchange with Outside Entities, n = 35

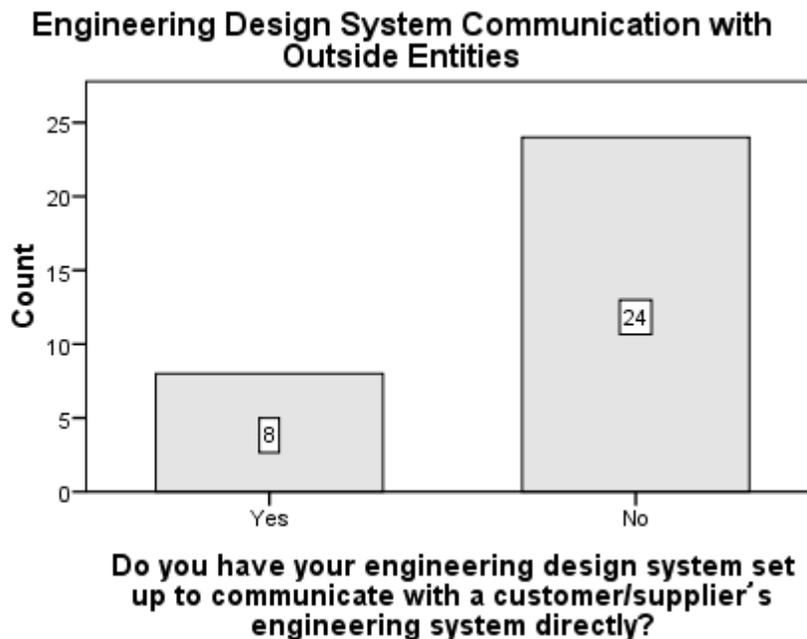


Figure 4.11 Engineering Design System Communication with Outside Entities, n = 32

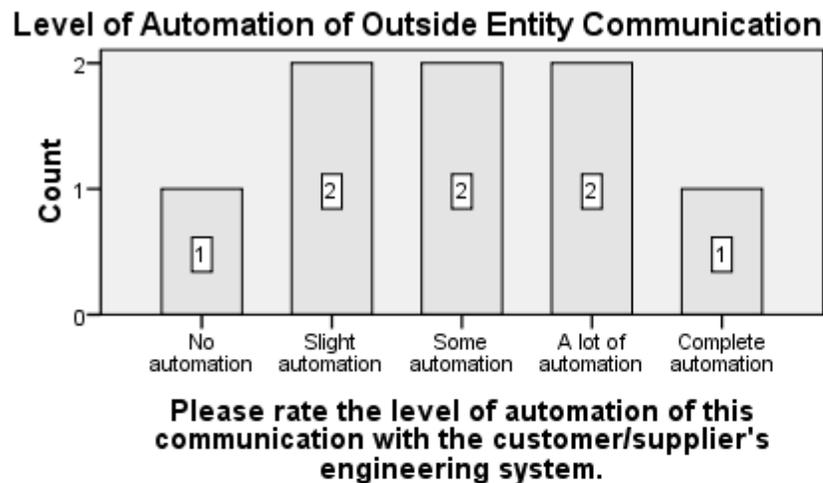


Figure 4.12 Level of Automation of Outside Entity Communication, n = 8

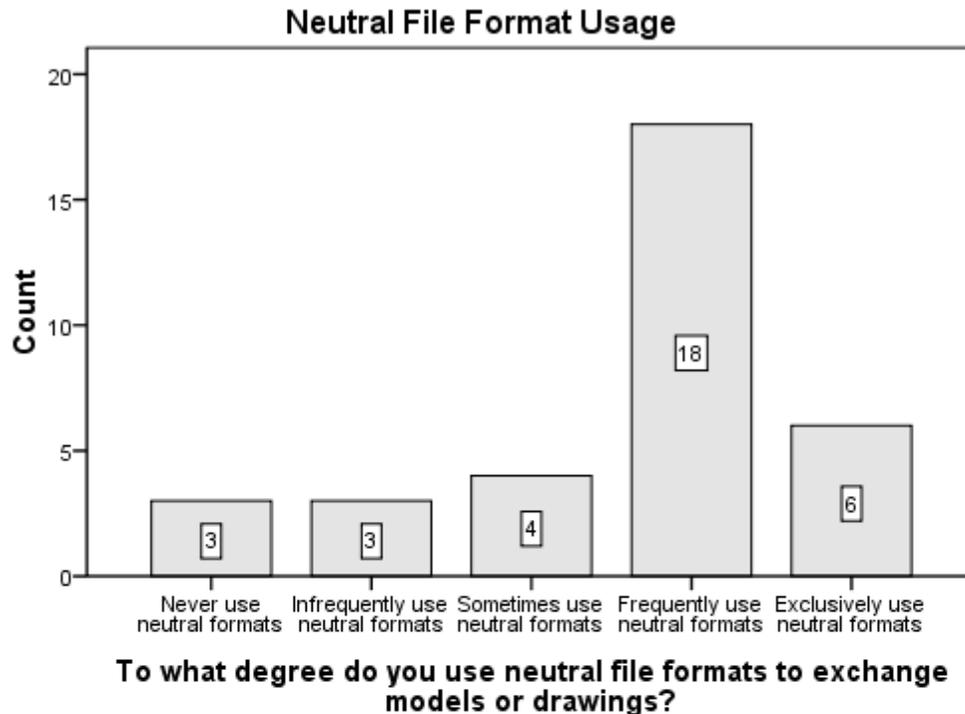


Figure 4.13 Neutral File Format Usage, n = 34

4.3.6.2.8. System Maintenance and Management

Larger companies have the benefit of being able to set aside groups of people who are completely dedicated to the management and maintenance of engineering design systems, but smaller manufacturers, especially those with less than 50 employees, may not have the luxury of a dedicated team. Therefore, it was important to collect data on how these smaller companies are coping with these potential difficulties.

The majority of companies reporting on the control and maintenance of their engineering design systems say their engineering organizations tend to take care of the system, see Table 4.10. Respondents who specified “other” often said that they themselves were in charge of it. Surprisingly, a large proportion of respondents said their systems get upgraded or otherwise maintained once a year, while the most of the rest reporting upgrades every 2 years or more, see *Figure 4.14*.

Table 4.10 *Who is your engineering design system managed and maintained by?*

Controlling Organizations			
	IT organization	Engineering organization	Other (specify)
Count	7	22	8

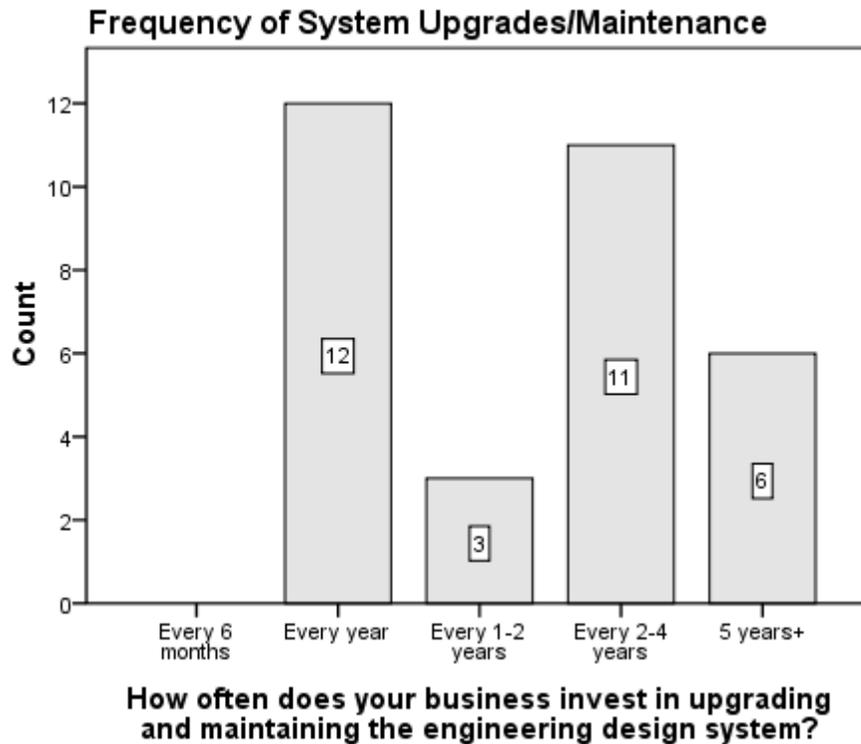


Figure 4.14 Frequency of System Upgrades/Maintenance, n = 32

4.3.6.2.9. System Monetization and Software Vendors

When asked how companies are monetizing their systems, meaning how they quantify their systems with money, many reported that costs were included in their overhead costs, or they use software on a trial basis. Others reported that they gauge system cost on a trial and error system, being cautious as they go, while others have written their own systems from the ground up using easily available software development tools and maintain the code themselves.

Typically software costs can be minimized by using related software packages provided by the same vendor. However, using software written by only one vendor can restrict companies in the functionalities their design teams can use. In general, more small manufacturers are using software written by different software vendors, but many still stay within one vendor umbrella, see *Figure 4.15*.

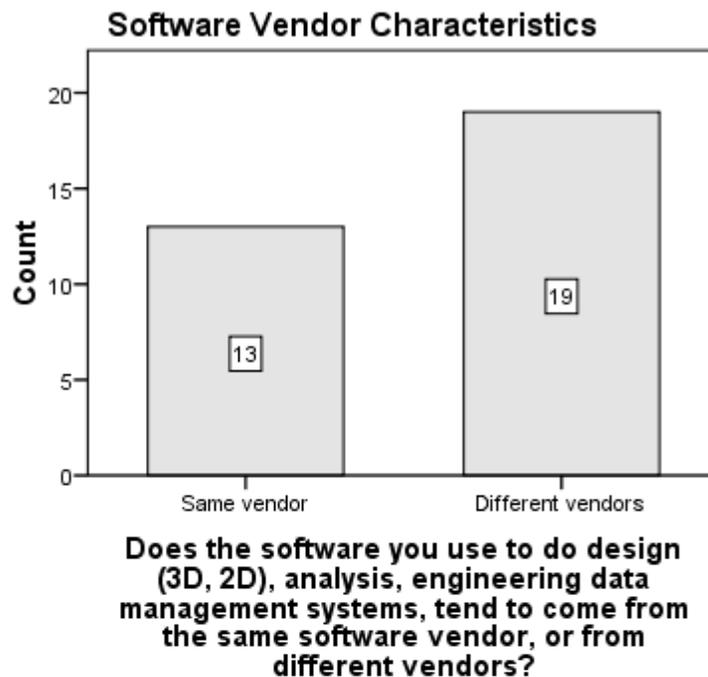


Figure 4.15 Software Vendor Characteristics, n = 32

4.3.6.2.10. Problem Solving & Attitudes Toward the System

When system errors or other problems crop up, the survey respondents typically contact their provider to fix the problem. Many have service agreements in place with software vendors to correct any problems that occur. A few have a formalized process or discovering what is causing the error, and some have a person within the organization that they contact first before calling for technical support from the software vendor.

Given that problems occur in any system that handles complex data that is critical for a company's survival, measuring the respondent's impressions of how their company's system has affected the organization as a whole, particularly how people tend to do their jobs. In general, respondents felt that their engineering design systems contributed to an environment of concurrent engineering, though some felt there was little to no contribution, see *Figure 4.16*. About half of respondents felt their engineering design system did put some type of restriction on the way they would like to do engineering design, but half felt there was no restriction at all, see *Figure 4.17*. Also, the majority of respondents reported that their design system meets some or most of their expectations for what it should be able to accomplish, but only a handful reported that these systems met all their expectations, see *Figure 4.18*. This may be due to the way the system was initially presented to them before implementation.

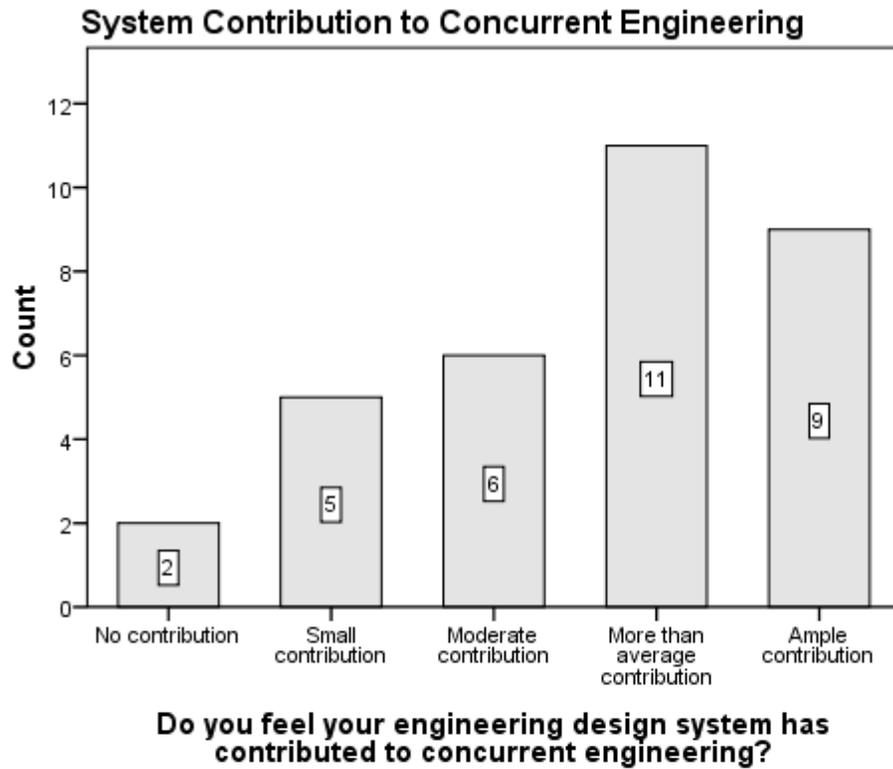


Figure 4.16 System Contribution to Concurrent Engineering, n = 33

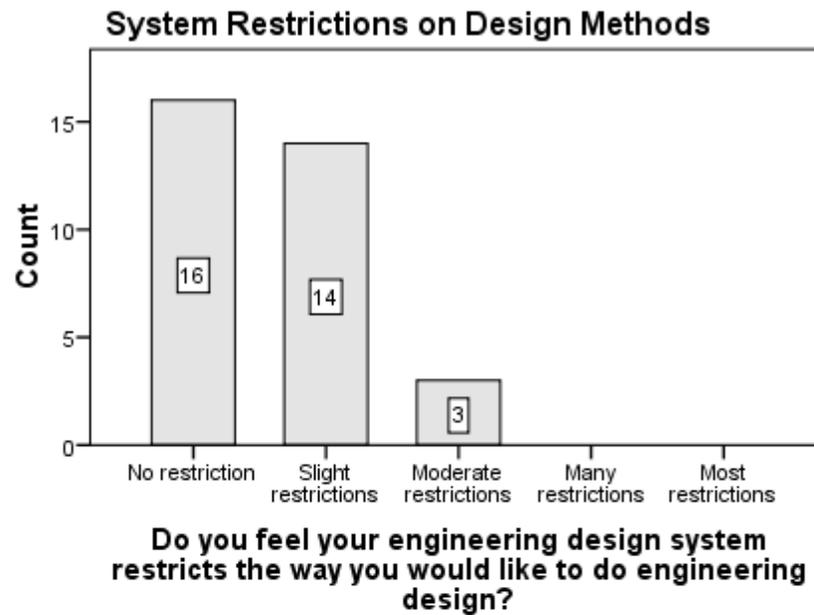


Figure 4.17 System Restrictions on Design Methods, n = 33

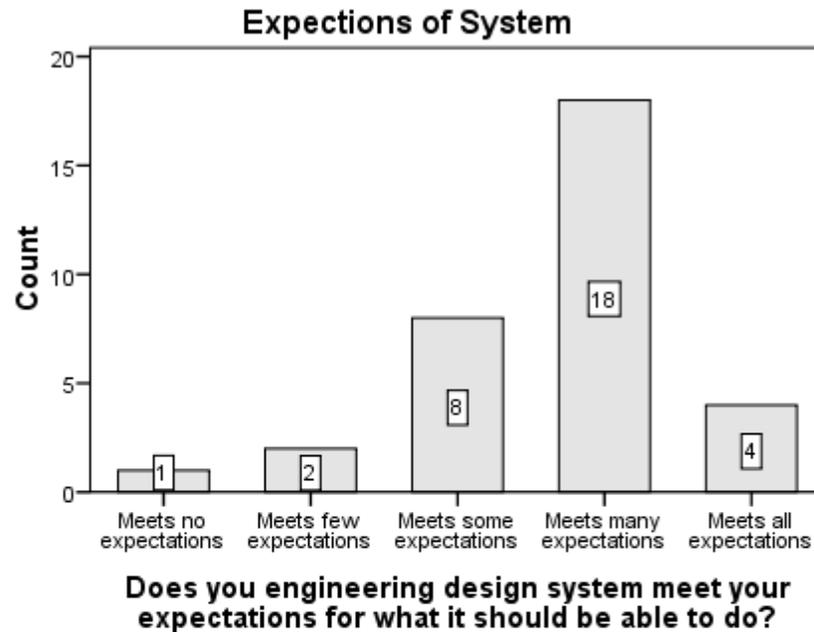


Figure 4.18 Expectations of System, n = 33

4.3.6.3. Comparison of Variables

Simple frequencies of responses reveal some interesting facts about how small manufacturers are handling PDM, but it does not come close to telling the whole picture. The goal of this study is to identify common characteristics of small manufacturers that show what their collective experiences have been with PDM. Therefore, it is important to attempt to correlate related variables together to see if there are any relationships between characteristics to begin to build a picture of what these small manufacturers are experiencing and what lies ahead of them as technology advances and engineering design evolves.

What follows is a breakdown by question/variable and how it relates to other pertinent questions/variables within the study. This analysis is accomplished using chi-square analysis, sometimes using multiple answer datasets, to determine how much of the relationship is due to chance. Typically a threshold of Pearson(p) <.05 must be attained for a disproval of the null hypothesis. In this case, the null hypothesis is to assume there is no relationship

between any variables in the study, and therefore if Pearson's value is less than .05, a relationship is assumed and mentioned.

4.3.6.3.1. Existence of Engineering Design System vs. Others

The survey split up all respondents into two major groups: those whose companies had a digital system specifically for dealing with engineering design data, and those whose company did not. This makes for an interesting distinction because it helps to show some characteristics of companies that have not yet adopted a PDM system of some sort. There may be relationships between industries, data format usage, personnel levels, and location information and any of those variables may be related to the fact that companies have or have not adopted PDM systems. Companies with a certain number of people might be more likely to adopt PDM systems, or those in a certain industry. Therefore, correlations were done on these variables in relation to the presence or lack of a PDM system.

The first variable that was looked at was the presence of a PDM-type system in relation to the company's industry, see Table 4.11. From the data, it appears there is no relationship between having a PDM system and which industry the company tends to be in. Generally the numbers for each industry was evenly split between companies that have a digital engineering data system and those that don't.

Table 4.11 Crosstabulation, Digital System Presence vs. Industry

		Digital Engineering Data System				Total	
		Yes		No			
		Count	% of Total	Count	% of Total	Count	% of Total
Industry	Aerospace	0	.0%	2	2.1%	2	2.1%
	Defense	2	2.1%	0	.0%	2	2.1%
	Industrial Equipment	17	17.5%	22	22.7%	39	40.2%
	Automotive	6	6.2%	5	5.2%	11	11.3%
	Consumer Products	4	4.1%	6	6.2%	10	10.3%
	Medical	0	.0%	1	1.0%	1	1.0%
	Other (specify)	10	10.3%	15	15.5%	25	25.8%
	Combination of Above	3	3.1%	4	4.1%	7	7.2%
	Total	42	43.3%	55	56.7%	97	100.0%
Chi-Square Test		Value		df		2-side Signif.	
Pearson Chi-Square		5.634		7		.583	

The number of employees in a manufacturing organization could very well have a relationship with whether or not that company has adopted a PDM system. According to the existing data, there isn't a significant relationship between employee levels and the adoption of a PDM system, although the probability is only .098, which could safely be stated as approaching significance, see Table 4.12. Judging from the percentages alone, it would appear that as companies gain employees, they may be more likely to adopt a PDM system.

Table 4.12 Crosstabulation, Digital System Presence vs. Employee Count

		Digital Engineering Data System					
		Yes		No		Total	
		Count	% of Total	Count	% of Total	Count	% of Total
# of Employees	< 10	8	8.2%	21	21.6%	29	29.9%
	10 - 49	19	19.6%	24	24.7%	43	44.3%
	50 - 99	6	6.2%	5	5.2%	11	11.3%
	100 - 299	9	9.3%	4	4.1%	13	13.4%
	300 - 499	0	.0%	1	1.0%	1	1.0%
	Total	42	43.3%	55	56.7%	97	100.0%
Chi-Square Test		Value		df		2-side Signif.	
Pearson Chi-Square		7.821		4		.098	

While PDM systems endeavor to unite those who are doing engineering design and standardize processes and create consistency, it can get complicated when being used across different sites, for a company of any size. However, it may be possible that having a system of some sort that spans across multiple locations might be better than no system at all. Most likely due to the majority of the companies in this sample being located at only one location, there appears to be no significant relationship between the adoption of an engineering design system and the geographical spread of engineering locations, see Table 4.13.

Table 4.13 *Crosstabulation, Digital System Presence vs. Locations*

		Digital Engineering Data System					
		Yes		No		Total	
		Count	% of Total	Count	% of Total	Count	% of Total
# of Locations	One location	33	36.3%	46	50.5%	79	86.8%
	More than one location	7	7.7%	5	5.5%	12	13.2%
	Total	40	44.0%	51	56.0%	91	100.0%
Chi-Square Test		Value		df		2-side Signif.	
Pearson Chi-Square		1.160		1		.281	
Continuity Correction		.585		1		.444	

There could also possibly be a correlation between companies who are either OEMs or suppliers, and whether or not they've adopted a PDM system, see Table 4.14. However, according to the data, there appears to be no relationship whatsoever.

Table 4.14 *Crosstabulation, Digital System Presence vs. Customer/Supplier Relationship*

		Digital Engineering Data System					
		Yes		No		Total	
		Count	% of Total	Count	% of Total	Count	% of Total
Relationship Type	OEM	12	13.0%	13	14.1%	25	27.2%
	Supplier	17	18.5%	19	20.7%	36	39.1%
	Both	12	13.0%	19	20.7%	31	33.7%
	Total	41	44.6%	51	55.4%	92	100.0%
Chi-Square Test		Value		df		2-side Signif.	
Pearson Chi-Square		.653		2		.722	

PDM systems naturally became the database companion to the increasing use of digital file formats, and thus there could easily be a correlation between

companies who are using 2D and 3D digital design formats and those who've adopted an electronic engineering data system. Although the probability of this is not below the .05 threshold needed to rule out the null hypothesis, it is approaching significance, meaning there may very well be some type of connection, especially for companies using 3D data, according to the percentages, see Table 4.15.

Table 4.15 *Crosstabulation, Digital System Presence vs. Digital Formats*

		Digital Engineering Data System				Total	
		Yes		No			
		Count	% of Total	Count	% of Total	Count	% of Total
Digital Format Used	All	0	.0%	2	2.2%	2	2.2%
	3D only	19	21.3%	11	12.4%	30	33.7%
	2D only	11	12.4%	20	22.5%	31	34.8%
	2D & 3D	8	9.0%	8	9.0%	16	18.0%
	2D & Other	2	2.2%	1	1.1%	3	3.4%
	Other Only	1	1.1%	6	6.7%	7	7.9%
	Total	41	46.1%	48	53.9%	89	100.0%
Chi-Square Test		Value		df		2-side Signif.	
Pearson Chi-Square		10.163		5		.071	

4.3.6.3.2. Other Significance in Entire Sample Comparisons

When testing for significant correlations between all the possible variables for the entire sample taking the survey, before the sample was filtered for having implemented a PDM system, a few other interesting comparisons appeared that are worth mentioning. Many comparisons, such as Industry vs. # of Locations, Employee Count vs. Data Format, and Industry vs. Customer/Supplier Relationship, yielded significance levels in the range of .7 to .4, and thus are not detailed here. However, a few tests in particular yielded significant or approaching significance levels that are detailed here.

The first comparison that yields near significant results is a comparison between industry and data format used, see Table 4.16. It's possible that certain industries tend to use different digital formats and there may be a relationship. According to the data, although it's not possible rule out the null hypothesis of no relationship, there is certainly a trend suggesting that there could be a relationship between the two variables due to the fact that Pearson's r is .06. The majority of companies reporting as using 2D and 3D formats tend to be in the Industrial Equipment and "other" industries

Table 4.16 Crosstabulation, Industry vs. Digital Formats

			Digital Design Format						
			All	3D	2D	Other	2D & 3D	2D & Other	Total
Industry	Aerospace	Count	0	1	0	1	0	0	2
		% of Total	.0%	1.1%	.0%	1.1%	.0%	.0%	2.2%
	Defense	Count	0	1	1	0	0	0	2
		% of Total	.0%	1.1%	1.1%	.0%	.0%	.0%	2.2%
	Industrial Equipment	Count	0	12	13	1	13	0	39
		% of Total	.0%	12.9%	14.0%	1.1%	14.0%	.0%	41.9%
	Automotive	Count	0	4	2	0	4	0	10
		% of Total	.0%	4.3%	2.2%	.0%	4.3%	.0%	10.8%
	Consumer Products	Count	1	2	6	1	0	0	10
		% of Total	1.1%	2.2%	6.5%	1.1%	.0%	.0%	10.8%
	Medical	Count	0	0	1	0	0	0	1
		% of Total	.0%	.0%	1.1%	.0%	.0%	.0%	1.1%
	Other (specify)	Count	0	9	7	4	1	2	23
		% of Total	.0%	9.7%	7.5%	4.3%	1.1%	2.2%	24.7%
	Combo of Above	Count	1	3	1	0	0	1	6
		% of Total	1.1%	3.2%	1.1%	.0%	.0%	1.1%	6.5%
Total		Count	2	32	31	7	18	3	93
		% of Total	2.2%	34.4%	33.3%	7.5%	19.4%	3.2%	100.0%
Chi-Square Test		Value	df			2-side Signif.			
Pearson Chi-Square		48.828	35			.060			

Another obvious relationship is between the number of employees a company has and the number of locations that engineering design takes place in. With a Pearson's r of less than .001, it is quite obvious there is a connection between these two variables, see Table 4.17. In general, companies with fewer

employee counts have only one location, but generally as companies grow to more than 50 employees, locations increase as well.

Table 4.17 *Crosstabulation, Employee Count vs. Locations*

		How many locations does your company do engineering design?			
		One location	More than one location	Total	
# of Employees	< 10	Count	31	0	31
		% of Total	28.4%	.0%	28.4%
	10 - 49	Count	48	3	51
		% of Total	44.0%	2.8%	46.8%
	50 - 99	Count	10	3	13
		% of Total	9.2%	2.8%	11.9%
	100 - 299	Count	6	7	13
		% of Total	5.5%	6.4%	11.9%
	300 - 499	Count	0	1	1
		% of Total	.0%	.9%	.9%
Total		Count	95	14	109
		% of Total	87.2%	12.8%	100.0%
Chi-Square Test		Value	df	2-side Signif.	
Pearson Chi-Square		34.302	4	.000	

While not strongly significant, a relationship between employee count and the types of customer/supplier relationships the company engages in may be related. In general, companies with employee counts between 10 and 50 tend to supply of some sort, with fewer of those company sizes being OEMs only, see Table 4.18.

Table 4.18 Crosstabulation, Employee Count vs. Customer/Supplier Relationship

		Is your company an original equipment manufacturer (OEM), supplier only, or both supplier and OEM?				
		OEM Only	Supplier Only	Both OEM and Supplier	Total	
# of Employees	< 10	Count	10	14	8	32
		% of Total	9.1%	12.7%	7.3%	29.1%
	10 - 49	Count	9	19	23	51
		% of Total	8.2%	17.3%	20.9%	46.4%
	50 - 99	Count	2	7	4	13
		% of Total	1.8%	6.4%	3.6%	11.8%
	100 - 299	Count	7	4	2	13
		% of Total	6.4%	3.6%	1.8%	11.8%
	300 - 499	Count	0	1	0	1
		% of Total	.0%	.9%	.0%	.9%
Total		Count	28	45	37	110
		% of Total	25.5%	40.9%	33.6%	100.0%
Chi-Square Test		Value	df	2-side Signif.		
Pearson Chi-Square		12.832	8	.118		

Another interesting comparison of variables is the one between companies that have adopted certain digital formats and their customer/supplier relationship. It's quite possible that companies who tend to act as both OEMs and suppliers have more complicated data needs and therefore have started adopting digital formats that are more cohesive with having to communicate data to other organizations in a variety of formats. Although in this case, the correlation is .2, it is one of the more significant comparisons for this subset of variables, see Table 4.19.

Table 4.19 Crosstabulation, Digital Format vs. Customer/Supplier Relationship

		Is your company an original equipment manufacturer (OEM), supplier only, or both supplier and OEM?							
		OEM Only		Supplier Only		Both OEM and Supplier		Total	
		Count	% of Total	Count	% of Total	Count	% of Total	Count	% of Total
Digital Design Format	All	0	.0%	0	.0%	2	2.2%	2	2.2%
	3D	9	9.9%	11	12.1%	12	13.2%	32	35.2%
	2D	9	9.9%	10	11.0%	11	12.1%	30	33.0%
	Other	2	2.2%	4	4.4%	0	.0%	6	6.6%
	2D & 3D	5	5.5%	5	5.5%	8	8.8%	18	19.8%
	2D & Other	0	.0%	3	3.3%	0	.0%	3	3.3%
	Total	25	27.5%	33	36.3%	33	36.3%	91	100.0%
Chi-Square Test		Value		df		2-side Signif.			
Pearson Chi-Square		13.450		10		.200			

4.3.6.3.3. Comparisons of Companies with PDM Systems

The following data involves only companies that reported having an engineering design system. This is approximately 35 responses, depending on individual circumstances. It's important to note while generally 35 responses would represent a representative sample to make statistically sound inferences about a population, it may not be enough for completely reliable chi-square type statistics. This is complicated by the fact that most questions are not of a binary nature, which spreads out possible responses, lowers individual cell counts, and may further skew the results. This will be discussed in more detail in Chapter 5, but it is important to mention here. Despite the relatively low number of respondents for this portion of the survey, a number of interesting relationships were found that will be further explored.

The first comparison of variables that yielded an interesting result was the interaction between respondents' level of involvement with the system and their expectations of that system and how it has met their expectations, see Table

4.20. Although not technically significant with a Pearson's r of .156, it is important to note that respondents who report being very or extremely involved tend to feel like their engineering design system has met many of their expectations, but not all. This may be due to the fact that those who are most familiar with these systems had more realistic expectations of how the system would behave before and during implementation.

Table 4.20 *Crosstabulation, Involvement Level vs. Expectations Met*

		Does your engineering design system meet your expectations for what it should be able to do?						
		None	Few	Some	Many	All	Total	
Level of Involvement	Slightly Involved	Count	0	0	0	2	0	2
	% of Total		.0%	.0%	.0%	5.7%	.0%	5.7%
	Somewhat Involved	Count	1	0	2	1	0	4
	% of Total		2.9%	.0%	5.7%	2.9%	.0%	11.4%
Very Involved	Count	0	2	5	8	2	17	
	% of Total		.0%	5.7%	14.3%	22.9%	5.7%	48.6%
Extremely Involved	Count	0	0	1	8	3	12	
	% of Total		.0%	.0%	2.9%	22.9%	8.6%	34.3%
Total		Count	1	2	8	19	5	35
		% of Total	2.9%	5.7%	22.9%	54.3%	14.3%	100.0%
Chi-Square Test		Value	df			2-side Signif.		
Pearson Chi-Square		16.842	12			.156		

A more interesting statistic in the same vein is the relationship between involvement level and attitudes towards how the system enables the finding of information. It appears that users who rated themselves as "very involved" tend to feel that the system makes finding information slightly faster, while those who rated themselves as "extremely involved" feel the system makes finding

information much faster, see Table 4.21. Furthermore, with a Pearson's r of .025, this correlation is most likely not due to chance, and therefore a true relationship can be predicted between these two variables.

Table 4.21 *Crosstabulation, Involvement Level vs. Effect on Time to Find Information*

		Rate the effect the engineering design system has on the time it takes to find information to complete a task.					
			Makes finding info slightly slower	No effect on time to find info (Neutral)	Makes finding info slightly faster	Makes finding info much faster	Total
Level of Involvement	Slightly Involved	Count	1	1	0	0	2
		% of Total	2.8%	2.8%	.0%	.0%	5.6%
	Somewhat Involved	Count	0	2	1	1	4
		% of Total	.0%	5.6%	2.8%	2.8%	11.1%
	Very Involved	Count	2	3	8	5	18
		% of Total	5.6%	8.3%	22.2%	13.9%	50.0%
	Extremely Involved	Count	0	3	0	9	12
		% of Total	.0%	8.3%	.0%	25.0%	33.3%
	Total	Count	3	9	9	15	36
		% of Total	8.3%	25.0%	25.0%	41.7%	100%
Chi-Square Test		Value	df		2-side Signif.		
Pearson Chi-Square		19.022	9		.025		

The next comparison of variables is between the time when companies enter information into their design systems, and whether or not they use workflows, see Table 4.22. Generally it would be assumed that companies who want to use workflows are forced to enter as much data as possible into the system at the beginning of a project, but that would be an assumption. Although

the Pearson's r is not quite low enough to completely reject the null hypothesis of no relationship at .065, it is approaching significance which would support the natural assumption that these variables are related.

Table 4.22 *Crosstabulation, Data Entry Timing vs. Workflow Usage*

		To what extent do you use workflows in your engineering design system?					Total	
		None	Once in a while	Some- times	Frequ- ently	Exten- sively		
When is data entered?	As much as possible at the beginning	Count % of Total	8 20.0%	1 2.5%	7 17.5%	3 7.5%	3 7.5%	22 55.0%
	Shortly into design process, then start entering data	Count % of Total	1 2.5%	2 5.0%	0 .0%	1 2.5%	0 .0%	4 10.0%
	Design process is almost over before entering data	Count % of Total	3 7.5%	0 .0%	0 .0%	0 .0%	0 .0%	3 7.5%
	Design ends, then enter the data (mostly for archival)	Count % of Total	2 5.0%	2 5.0%	0 .0%	0 .0%	3 7.5%	7 17.5%
	Other	Count % of Total	0 .0%	2 5.0%	0 .0%	1 2.5%	1 2.5%	4 10.0%
	Total	Count % of Total	14 35.0%	7 17.5%	7 17.5%	5 12.5%	7 17.5%	40 100.0%
Chi-Square Test		Value	df		2-side Signif.			
Pearson Chi-Square		25.297	16		.065			

Two other possibly related variables are when companies tend to enter data relative to how often they invest in upgrades and maintenance of their

systems. It would make sense that companies that enter as much data into the system at the beginning of the design process as possible would also see their system as vital to their design process and therefore be more willing to invest resources into its maintenance and upkeep, see Table 4.23. Although the significance level for this comparison is not high enough to rule out chance, the relationship between the two variables does appear to be approaching significance, with a trend towards companies who use their PDM systems as an integral tool in their design process investing either every year or every 2-4 years.

Table 4.23 Crosstabulation, Data Entry Timing vs. System Investment Frequency

		How often does your business invest in upgrading and maintaining the engineering design system?				Total	
		Every year	Every 1-2 years	Every 2-4 years	5 years+		
When is data entered?	As much as possible at the beginning	Count % of Total	8 23.5%	1 2.9%	9 26.5%	1 2.9%	19 55.9%
	Shortly into design process, then start entering data	Count % of Total	2 5.9%	0 .0%	1 2.9%	1 2.9%	4 11.8%
	Design process is almost over before entering data	Count % of Total	0 .0%	0 .0%	1 2.9%	0 .0%	1 2.9%
	Design ends, then enter the data (mostly for archival)	Count % of Total	3 8.8%	1 2.9%	0 .0%	3 8.8%	7 20.6%
	Other	Count % of Total	0 .0%	1 2.9%	0 .0%	2 5.9%	3 8.8%
Total		Count % of Total	13 38.2%	3 8.8%	11 32.4%	7 20.6%	34 100%
Chi-Square Test		Value	df		2-side Signif.		
Pearson Chi-Square		18.013	12		.115		

PDM systems are generally designed to function in a certain basic way, and then companies are able to decide on a case-by-case basis whether they want to use additional functionality that is offered. Workflow usage is one of these added functionalities that companies may or may not choose to use, but typically when a company is looking to standardize and automate release processes in particular, they can be a valuable asset to have in a PDM system. Likewise, businesses looking to reuse their engineering data in other places around the company may use workflows to help push the necessary data to the

people who need it, without a manual process involved. The connection between these two variables is approaching significance, showing that companies who are attempting to share engineering data with other parts of their business tend to use workflows more frequently than those businesses that are not, see Table 4.24.

Table 4.24 *Crosstabulation, Workflow Usage vs. Design System Data Sharing*

		Does your engineering design system share data with other parts of the business beyond engineering?			
		Yes	No	Total	
Workflow usage	None	Count	5	7	12
		% of Total	13.5%	18.9%	32.4%
	Once in a while	Count	5	2	7
		% of Total	13.5%	5.4%	18.9%
	Sometimes	Count	6	0	6
		% of Total	16.2%	.0%	16.2%
	Frequently	Count	4	1	5
		% of Total	10.8%	2.7%	13.5%
	Extensively	Count	5	2	7
		% of Total	13.5%	5.4%	18.9%
	Total	Count	25	12	37
		% of Total	67.6%	32.4%	100.0%
Chi-Square Test		Value	df	2-side Signif.	
Pearson Chi-Square		7.002	4	.136	

The effects the system had on the time it takes to complete a task and the time it takes to find information to complete a task ended up being correlated as well. In general, survey respondents who reported that the system had no effect on the speed at which they were able to complete a design task also reported having no effect on the time it took to find information to complete a task. However, respondents who felt their engineering design systems made design tasks go much faster also felt finding information was much faster too, see Table

4.25. With a Pearson's r value of .018, these results are likely not due to chance. This is an interesting dichotomy that will be explored further in Chapter 5.

Table 4.25 *Crosstabulation, Effect on Design Task Time vs. Time to Find Information*

		Rate the effect the engineering design system has on the time it takes to find information to complete a task.					
			Makes finding info slightly slower	No effect on time to find info (Neutral)	Makes finding info slightly faster	Makes finding info much faster	Total
Effect on design task time	Slightly slower	Count % of Total	3 8.3%	0 .0%	2 5.6%	3 8.3%	8 22.2%
	No effect (Neutral)	Count % of Total	0 .0%	6 16.7%	3 8.3%	3 8.3%	12 33.3%
	Slightly faster	Count % of Total	0 .0%	1 2.8%	2 5.6%	1 2.8%	4 11.1%
	Much faster	Count % of Total	0 .0%	2 5.6%	2 5.6%	8 22.2%	12 33.3%
Total		Count % of Total	3 8.3%	9 25.0%	9 25.0%	15 41.7%	36 100.0%
Chi-Square Test		Value	df		2-side Signif.		
Pearson Chi-Square		20.067	9		.018		

Another interesting correlation that proved to be significant was the connection between whether an engineering design system shares data beyond just engineering, and how much effect the system has on finding information for a task. Respondents whose design system shares data tend to strongly feel the system makes finding information for their tasks faster, either slightly or much

faster, see Table 4.26. This may due to the fact that the design tasks in an integrated design system must pull information from more sources and thus a centralized location for data made finding information easier.

Table 4.26 *Crosstabulation, Effect on Time to Find Information vs. Design System Data Sharing*

			Does your engineering design system share data with other parts of the business beyond engineering?		
			Yes	No	Total
Effect on time to find info for task	Makes finding info slightly slower	Count	1	2	3
		% of Total	2.8%	5.6%	8.3%
	No effect on time to find info (Neutral)	Count	3	6	9
		% of Total	8.3%	16.7%	25.0%
	Makes finding info slightly faster	Count	7	2	9
	% of Total	19.4%	5.6%	25.0%	
	Makes finding info much faster	Count	13	2	15
		% of Total	36.1%	5.6%	41.7%
	Total	Count	24	12	36
		% of Total	66.7%	33.3%	100.0%
Chi-Square Test			Value	df	2-side Signif.
Pearson Chi-Square			9.200	3	.027

Attitudes towards concurrent engineering and how engineering design systems play a role in those attitudes are a constantly changing concept, especially with the rapid advance of technology to enable concurrent design. In an environment where a lot of data exchange and design changes are happening, concurrent design could potentially save businesses money by constantly iterating and improving communication between experts rather than over-the wall type engineering. From the data, a connection exists between the

level of concurrent engineering the system is requiring by its very existence and the frequency at which companies are exchanging data with their customers and suppliers, see Table 4.27. It appears that companies who frequently exchange data tend to feel their systems have contributed more to concurrent engineering than companies who infrequently exchange data with their customers and suppliers.

Table 4.27 Crosstabulation, Frequency of Data Exchange vs. Contribution to Concurrent Engineering

		Do you feel your engineering design system has contributed to concurrent engineering?						
		No contribution	Small contribution	Mode-rate contribution	More than average contribution	Ample contribution	Total	
Frequency of data exchange with customers & suppliers	Daily	Count	1	0	4	8	3	16
		% of Total	2.9%	.0%	11.4%	22.9%	8.6%	45.7%
	2-3 Times a Week	Count	0	0	2	2	2	6
		% of Total	.0%	.0%	5.7%	5.7%	5.7%	17.1%
	Once a Week	Count	0	1	1	1	1	4
		% of Total	.0%	2.9%	2.9%	2.9%	2.9%	11.4%
	2-3 Times a Month	Count	0	0	0	1	1	2
		% of Total	.0%	.0%	.0%	2.9%	2.9%	5.7%
	Once a Month	Count	0	2	0	0	0	2
		% of Total	.0%	5.7%	.0%	.0%	.0%	5.7%
	More than a month	Count	0	2	0	0	1	3
		% of Total	.0%	5.7%	.0%	.0%	2.9%	8.6%
	Never	Count	1	0	0	0	1	2
		% of Total	2.9%	.0%	.0%	.0%	2.9%	5.7%
Total	Count	2	5	7	12	9	35	
	% of Total	5.7%	14.3%	20.0%	34.3%	25.7%	100%	
Chi-Square Test		Value		df	2-side Signif.			
Pearson Chi-Square		36.247		24	.052			

It also appears that respondents whose companies are frequently exchanging data with their customers and suppliers - more than a few times each week - tend to feel that their engineering design systems do not place many restrictions on their engineering design process, see Table 4.28. This could be due to the fact that the data exchange capabilities of their design system are saving them time in other ways that affect how respondents feel about the

restrictions the system puts on them, or there could be other reasons for this correlation.

Table 4.28 Crosstabulation, Frequency of Data Exchange vs. Restrictions on Design Methods

		Do you feel your engineering design system restricts the way you would like to do engineering design?				
		No restriction	Slight restrictions	Moderate restrictions	Total	
Frequency of data exchange with customers & suppliers	Daily	Count	9	7	0	16
		% of Total	25.7%	20.0%	.0%	45.7%
	2-3 Times a Week	Count	2	4	0	6
		% of Total	5.7%	11.4%	.0%	17.1%
	Once a Week	Count	1	3	0	4
		% of Total	2.9%	8.6%	.0%	11.4%
	2-3 Times a Month	Count	0	1	1	2
		% of Total	.0%	2.9%	2.9%	5.7%
	Once a Month	Count	2	0	0	2
		% of Total	5.7%	.0%	.0%	5.7%
	More than a month	Count	3	0	0	3
		% of Total	8.6%	.0%	.0%	8.6%
Never	Count	0	0	2	2	
	% of Total	.0%	.0%	5.7%	5.7%	
Total	Count	17	15	3	35	
	% of Total	48.6%	42.9%	8.6%	100.0%	
Chi-Square Test		Value	df	2-side Signif.		
Pearson Chi-Square		36.556	12	.000		

Also in general, there appears to be a significant relationship between the frequency of data exchange a customer experiences with its customers and suppliers, and whether their design system meets their expectations for its functionality, see Table 4.29. Most respondents who reported exchanging the

data at least a few times a week feel that their systems are meeting most of their expectations.

Table 4.29 Crosstabulation, Frequency of Data Exchange vs. Expectations Met

		Does your engineering design system meet your expectations for what it should be able to do?					Total	
		None	Few	Some	Many	All		
Frequency of data exchange with customers & suppliers	Daily	Count	0	1	2	11	2	16
		% of Total	.0%	2.9%	5.7%	31.4%	5.7%	45.7%
	2-3 Times a Week	Count	0	0	1	4	1	6
		% of Total	.0%	.0%	2.9%	11.4%	2.9%	17.1%
	Once a Week	Count	0	0	2	1	1	4
		% of Total	.0%	.0%	5.7%	2.9%	2.9%	11.4%
	2-3 Times a Month	Count	0	0	2	0	0	2
		% of Total	.0%	.0%	5.7%	.0%	.0%	5.7%
	Once a Month	Count	0	0	0	2	0	2
		% of Total	.0%	.0%	.0%	5.7%	.0%	5.7%
	More than a month	Count	0	1	1	0	1	3
		% of Total	.0%	2.9%	2.9%	.0%	2.9%	8.6%
	Never	Count	1	0	0	1	0	2
		% of Total	2.9%	.0%	.0%	2.9%	.0%	5.7%
Total	Count	1	2	8	19	5	35	
	% of Total	2.9%	5.7%	22.9%	54.3%	14.3%	100.0%	
Chi-Square Test		Value	df		2-side Signif.			
Pearson Chi-Square		36.742	24		.046			

More than a third of respondents who reported that they frequently use neutral file formats also report that their engineering design systems are managed and maintained by engineering departments only, see Table 4.30. This could be due to the fact that more companies reporting say their engineering departments are responsible for the design system, instead of IT or “other,” but there is a strong enough relationship to warrant a Pearson’s r of .013, suggesting this relationship is not due to chance.

Table 4.30 Crosstabulation, Neutral File Format Usage vs. Controlling Organization

		Who is your engineering design system managed and maintained by?							Total
		IT	Eng	Other	IT & Eng	Eng & Other	IT & Other		
Degree of neutral file format usage	Never	Count	1	0	1	1	0	0	3
		% of Total	2.9%	.0%	2.9%	2.9%	.0%	.0%	8.6%
	Infrequently	Count	0	2	0	0	0	1	3
		% of Total	.0%	5.7%	.0%	.0%	.0%	2.9%	8.6%
	Sometimes	Count	0	3	0	0	1	0	4
		% of Total	.0%	8.6%	.0%	.0%	2.9%	.0%	11.4%
Frequently	Count	2	13	3	1	0	0	19	
	% of Total	5.7%	37.1%	8.6%	2.9%	.0%	.0%	54.3%	
Exclusively	Count	0	1	4	1	0	0	6	
	% of Total	.0%	2.9%	11.4%	2.9%	.0%	.0%	17.1%	
Total	Count	3	19	8	3	1	1	35	
	% of Total	8.6%	54.3%	22.9%	8.6%	2.9%	2.9%	100.0%	
Chi-Square Test		Value	df		2-side Signif.				
Pearson Chi-Square		36.699	20		.013				

Another interesting correlation between variables was the one between the level of concurrent engineering these design systems tend to create, and how the systems met expectations. It appears that as systems tend to contribute more to concurrent engineering, respondents felt the systems met more and more of their expectations, see Table 4.31. That's partially to be expected considering that product lifecycle management as a concept is based on the idea of concurrent engineering and product focus rather than process focus.

Table 4.31 *Crosstabulation, Contribution to Concurrent Engineering vs. Expectations Met*

			Does your engineering design system meet your expectations for what it should be able to do?					
			Meets no expectations	Meets few expectations	Meets some expectations	Meets many expectations	Meets all expectations	Total
Contribution to Concurrent Engineering	No contribution	Count % of Total	1 2.9%	1 2.9%	0 .0%	0 .0%	0 .0%	2 5.7%
	Small contribution	Count % of Total	0 .0%	1 2.9%	2 5.7%	2 5.7%	0 .0%	5 14.3%
	Moderate contribution	Count % of Total	0 .0%	0 .0%	3 8.6%	4 11.4%	0 .0%	7 20.0%
	More than average contribution	Count % of Total	0 .0%	0 .0%	1 2.9%	8 22.9%	3 8.6%	12 34.3%
	Ample contribution	Count % of Total	0 .0%	0 .0%	2 5.7%	5 14.3%	2 5.7%	9 25.7%
	Total	Count % of Total	1 2.9%	2 5.7%	8 22.9%	19 54.3%	5 14.3%	35 100%
Chi-Square Test		Value	df		2-side Signif.			
Pearson Chi-Square		35.171	16		.004			

The final comparison to be made is the correlation between how respondents felt their design system restricts their design methods and whether the system meets expectations or not. In general, users who feel there are no restrictions at all tend to feel that the system meets many or all of their expectations, while respondents who feel there are slight to moderate restrictions feel the systems don't meet as many of their expectations, see Table 4.32. This

is an interesting relationship because it shows that users who are more skeptical about their systems' capabilities and functionality tend to also feel like it's not living up to what they expected it would. This could be a symptom of just poor systems, or something at a deeper level such as attitudes and fear of how the system has changed their job.

Table 4.32 *Crosstabulation, Restrictions on Design Methods vs. Expectations Met*

		Does your engineering design system meet your expectations for what it should be able to do?					Total	
		Meets no expectations	Meets few expectations	Meets some expectations	Meets many expectations	Meets all expectations		
System restricts design process?	None	Count	0	1	3	9	4	17
		% of Total	.0%	2.9%	8.6%	25.7%	11.4%	48.6%
	Slight	Count	0	1	4	9	1	15
		% of Total	.0%	2.9%	11.4%	25.7%	2.9%	42.9%
	Mode- rate	Count	1	0	1	1	0	3
		% of Total	2.9%	.0%	2.9%	2.9%	.0%	8.6%
Total		Count	1	2	8	19	5	35
		% of Total	2.9%	5.7%	22.9%	54.3%	14.3%	100%
Chi-Square Test			Value		df		2-side Signif.	
Pearson Chi-Square			13.697		8		.090	

4.3.6.4. Summary of Comparisons

As detailed above, there are a variety of different significant or approaching significant variables that, when compared through statistical chi-square methods, produce statistically significant relationships that are not due to

chance. Many other comparisons produce near-significant results that, while unable to rule out the effect of chance completely, still tell an interesting story.

Because the entire sample was effectively split into two groups, respondents who reported that their companies have a system dedicated to handling design data, and those that do not, both groups were large enough to do statistically meaningful tests on to make inferences about the larger population of small manufacturers. As mentioned earlier, the group of respondents who reported having a PDM type of system was much smaller, and for some comparisons using chi-square methods, significance values must be examined closely due to low cell counts, depending on the options given for the question.

However, despite this threat to validity, a lot of interesting facts were gleaned from the data, such as that the primary usage of engineering design systems is the storage of manufacturing information for these small businesses, and are using neutral file formats frequently. They also tend to get their software from different vendors, but feel that their design systems are not posing any major restrictions on their engineering processes and their systems are generally meeting their expectations. There also seems to be interactions between a variety of different variables such as level of involvement in the system when compared with the perceived effect on the time it takes to find information to perform a task. Others include the frequency of exchanging data with outside entities versus how the system has contributed to concurrent engineering, and the usage of neutral file formats versus the organizational group that manages the design system.

4.4. Chapter Summary

This chapter presented all the data that was generated during the course of this study. It detailed the initial qualitative data collection which was then coded into a set of survey questions that comprised the quantitative piece of the study where conclusions could be made about relationships between different

characteristics small manufacturers tend to have in common. The qualitative interviews were discussed, including the participant demographics and how the interviews were conducted and coded. Once the codes and questions were completed, the chapter discussed the details of the survey including how participants were collected, how the survey was delivered, and how the data was collected. The chapter also went into detail about the findings of those relationships and presented variable comparisons that were significant or approaching significance. The next chapter will be a discussion of the results and recommendations for future research.

CHAPTER 5. DISCUSSION & RECOMMENDATIONS

5.1. Introduction

The main goal of this study was to identify common traits of small manufacturing businesses that have adopted a digital PDM tool, and how that technology has influenced them. It was also important to collect information about those organizations who have not yet implemented a PDM system, to see if there are any relationships to be taken advantage of when considering the move to adopt an engineering design system.

5.2. Discussion of Small Manufacturer Characteristics

It's important to first discuss the basics of what kind of business demographics were found from the survey sample. Although most businesses were located in Indiana, due to the contact collection method, it quickly became clear that the majority of the small manufacturers classified themselves as being in the industrial equipment industry. Admittedly, this is a broad category and covered many different areas. Many companies cited that they were in the construction industry, sometimes manufacturing supplies, others working on hydraulics systems for highway construction machinery. When compared with some of the other industries, this group of manufacturers seems to really dominate the Indiana manufacturing community. They are about evenly split between having a PDM system and not having one, but the vast majority of them had fewer than 50 employees, versus some of the other industries such as companies in the automotive and other categories, which were more evenly dispersed in terms of employee counts.

By sending out a survey to a variety of companies, it's possible that more companies with smaller employee counts responded just due to the numbers of companies that are small within Indiana and by extension the US. This is reflective of the manufacturing industry in the US in general; while larger corporations make up the majority of the industry by sheer employee counts, there are far more individual smaller companies than large ones, and thus it makes sense that more small companies responded to the survey. There are simply more small companies in general. This seems to confirm the conclusion found during the review of literature that these smaller companies truly are important in that each one is different from the next, and although they don't employ the majority of employees in the manufacturing industry, they do compete with each other, and due to their smaller size and revenue levels, are more prone to economic rises and falls. Prior to the economic downturn in 2008, small manufacturers were increasing in numbers due to their advantages against larger competitors (Hise, 2007). However, it is difficult to gauge exactly how these small manufacturers are doing in 2010 given the economic climate. Despite the difficulties, it appears that in a survey of companies with fewer than 500 employees, companies that have less than 50 tend to be the most abundant.

In connection with the general trend towards employee counts less than 50, it also makes sense that the vast majority of reporting companies do engineering design at only one location. As stated earlier, generally PDM becomes more essential, while also more complicated, as companies start to expand to serve different markets and in design in different locations. However, because most respondents reported that their businesses are doing engineering design in only one location, their PDM and other IT systems needs are uncomplicated by the need to sync data across a wider network or over the internet, which is an advantage that many large OEMs, especially those that were interviewed during the first phase of the study, simply do not have.

Relationships with customers and suppliers was also surprising given the stereotype of small manufacturers as being mostly job shops that do little of their

own design. Although this was the case for some respondents, almost an equal amount of respondents were OEMs or acted as both suppliers and OEMs, doing much of their own engineering. However, whether the company was a supplier, OEM, or both, they almost all supply to or buy products from more than one other company. This is an important distinction because in so much of the literature small manufacturers are portrayed as being in a difficult position because they can be put into a supply chain, especially in the automotive industry, so that they are only supplying one company instead of many, and are put in a particularly vulnerable place economically. It's possible that due to the economy, small manufacturers have started to stratify more to ensure they are able to stay afloat in case a major customer either goes bankrupt or stops doing business with them.

Companies that act in an OEM role tend to buy parts that were both designed and manufactured by someone else, while companies acting in a supplier role are most likely to be designing and manufacturing their products. This is closer to the traditional model for customer and supplier relationships, but there are still a handful of companies that go against this model and have more complex relationships by only supplying or buying engineering design, or buying and selling parts that they designed but had someone else manufacture. This is an interesting space to explore because of the complexity across the entire industry, even within a subset like smaller manufacturers. Most large corporations are doing their own design and sending those designs to smaller manufacturers to make, or buying the design services of a smaller company, or doing their own design and manufacturing. One may not expect to see this type of variety at a smaller level, but it does exist. This may also further complicate the PDM and PLM space for smaller manufacturers due to the wide range of needs these companies are starting to manage their increasingly digital data.

Digital format was also an interesting result from the survey. According to the data, companies are using both 2D and 3D formats about equally the same. This is an encouraging trend for small businesses, which may not need 3D

design formats to define their products. However, many companies who answered “other” reported that they’re using drawings, rather than 2D digital tools. “Solidworks” was also a common response for those responding to the text entry for other digital formats, as if respondents didn’t fully grasp that Solidworks falls under both categories of 3D and 2D, depending on its application. Given that Dassault Systemes’ Solidworks has relatively deep penetration particularly in the small manufacturer population, this is an understandable response, although it is difficult to tell whether there was confusion about the question or evidence of a wider trend of Solidworks usage (Tara, 2003).

A very important statistic was the level of engineering design system usage within this sample of manufacturers. About 45% of respondents reported that their companies had a digital system dedicated to handling engineering design, but the slight majority does not. This is to be expected given the other characteristics of the sample, and will be discussed in later sections of this chapter.

5.2.1. Having a Design System vs. No System

Going into this study, an important and potentially useful comparison was the characteristics of companies that have engineering design systems versus those that have not yet adopted one. Discovering if there are any connections between traits companies who have a system can help other manufacturers that are trying to decide whether or not to adopt a new system.

Although in general no comparisons were directly significant, two variables in particular stood out as having some effect on whether or not a company has adopted a digital engineering design system: number of employees ($p=.098$), and the type of digital formats used to define design ($p=.071$). Both of these variables make sense to be connected to the presence of a design system because typically a company that has adopted digital formats as a method to define design needs places to store, manage, and archive all this data over time. Software vendors that sell 2D and 3D design tools also often have a file

management tool of some sort that they may offer to companies for a lower price when bundled with the design tool itself. Also, companies that use 3D tools were more likely to have a system versus companies that used 2D tools. This is an interesting distinction, which can really be best explained by the fact that 3D software vendors more often have a system that can be bundled with the 3D tool itself that was designed to be integrated together. 2D tools may be lacking in associative part management, which, for a company that does not necessarily need to maintain referential integrity between part files, could make a separate digital system for storing and managing 2D part files seem like a waste of resources.

Likewise, as the numbers of employees increased, companies were more likely to have a digital system for handling engineering data. This makes sense given that digital design systems are built to help organize data and ensure it gets to the right people in the company. With larger numbers of people, the added benefit of automating this process of data flow makes engineering design systems, PDM systems in particular, increasingly attractive.

5.2.2. Digital Formats, Employee Counts, and Customer/Supplier Relationships

On the same topic of digital file formats, a near significant relationship is shown between industry and the digital format being used ($p=.06$). In general, companies in the industrial equipment, defense, and automotive industries tended to gravitate towards 2D and 3D tools, while companies in consumer products and “other” use mostly 2D or other types of tools to define engineering data. This could be a good guideline to follow for companies in these industries who are looking at adopting different toolsets besides just a system for managing design data.

Another quite obvious connection was revealed regarding the number of employees in a company and whether they do engineering design at one location or many ($p<.001$). Companies with more employees tend to be more spread out, which is understandable. There is also a connection, though weaker, between

the number of employees in a company and what their customer/supplier relationship is like ($p=.118$). In general, companies who are suppliers tend to have fewer employees than those who are OEMs. This may be due to the increased manpower needed to do OEM tasks that include engineering design as well as manufacturing, as well as finding customers to sell products to, and manage suppliers to buy parts and products from. Suppliers, on the other hand, while equally complex, may have lower costs, and therefore manpower needs, if they are in a relationship where they don't need to do design themselves, or they are being contracted by an OEM to sell parts and therefore do not need as much personnel to handle customers or their own suppliers.

Also related to the customer/supplier relationship each company has, there is a slight correlation with the types of digital formats used and the type of relationship a company has with its customers and suppliers. Companies that tend to do supply only also are less likely to be using 2D and 3D digital tools when compared with other manufacturers that are filling both supply and OEM roles, who are more likely to be using 2D and 3D file formats to define engineering design. This further illuminates the type of culture these small manufacturers have; those supplying to other companies may have less incentive to update their engineering processes to include more modern forms of digital design formats because they potentially have less data that needs to be managed, and have less defined processes for dealing with orders by their customers.

5.2.3. Experience of PDM

Those companies who reported having some sort of engineering design system are the truly the target population of this study, because they can provide insight into how the use of PDM tools have affected the way they do engineering design, whether it has been a positive or negative change, and hopefully help draw conclusions that can help other small businesses in their decision on whether or not to adopt a PDM system, and which tool will be best for them. As

mentioned before, large software vendors, particularly those providing advanced 3D modeling and analysis software, have traditionally overlooked the small manufacturer business segment in terms of creating tools that meet their specialized needs and marketing their tools to these businesses. However, more and more software vendors are recognizing the market potential in small and medium manufacturers and are attempting to make more streamlined out-of-the-box PDM solutions these companies with fewer resources (Kevan, 2009). In the meantime, it is good to examine some of the qualities small manufacturers with engineering data systems to get an idea of what lead them to adopt their systems.

To start, most respondents to the second part of the survey about engineering design systems reported that they were very or extremely involved in the system at their company. This is a generally good marker that the rest of the answers were relatively reliable, because it means that respondents were most likely generally knowledgeable about the systems used at their companies and their answers would be credible. This could be due to the fact that with such small companies, the upper management is more involved with the day to day activities of the business, and therefore are more knowledgeable about the details of their design systems than may be found at larger companies.

Respondents also report that they're using their systems primarily to store manufacturing information, and then as a general repository for data and product structure management and bills of materials. The term "manufacturing information" is very broad and tends to mean different things to different people, depending on the situation of each company. Based on text responses, it can be predicted that for many, this term means tooling information such as CNC programs and tooling standards. It also includes factory flow information, scheduling, and materials data. Of course many companies are using their systems to handle as much data as possible, including product structure management, configuration management, version control, and others. This indication, that the main use of engineering design systems is to store

manufacturing information, is an interesting result given that the traditional PDM tool is built mostly for engineering design itself and typically must be modified or added to better support manufacturing information. It also shows that these small manufacturers are not in the “PLM” mindset, in that they are focusing more on their processes than the product itself, which may be a good thing for them now, but long term may not be conducive with growth given the advance of technology and competition.

Another interesting piece of information is that most companies are being proactive in their usage of their design systems and entering as much data into it as possible at the beginning of the design process. This may seem obvious to larger companies, but smaller manufacturers are more used to paper-based systems and may be using an older digital system as a method of archiving design data. There are a handful of this sample that are using their systems for that, but the majority are attempting to put their data into the system as soon as possible, which would presumably be the main reason they implemented the system in the first place. However, despite this effort to integrate the system throughout the design process, most companies are not making use of automated workflows within the system. This could be due to the lack of a need for it; a company with 30 employees may find it easier to just email each other or stop by someone’s office to remind someone else that the data is now in that person’s hands for approval. The benefits of setting up a workflow that may be constantly changing may not be cost effective given the alternative, more manual way of routing information through a process. Standard processes for data flows may not exist in the first place. It could also be that their systems are not advanced enough to handle workflows effectively. Regardless, this is a good point to make in general for small manufacturers; that automated workflows are not always necessary, but well defined processes for data flow may help in cutting costs, even if it is a manual process.

The speed of tasks, particularly doing a design task and finding information, are usually major benefits cited by companies who have adopted a

robust PDM system (Philpotts, 1996). This benefit is also reflected in this study's sample of small manufacturers, where the majority of respondents report that their system makes design tasks faster or has no effect, and finding information in particular is either slightly or much faster. This is particularly important, because even though a smaller company may have a smaller amount of data through which to search, it may be coming from a wider variety of sources or over a larger period of time, and thus is not always in a standardized format. One of the interviewees in the first part of the study that worked for the smaller manufacturer cited this as a major benefit for his company. His coworkers often struggled to find older data because it was never in the newest format and thus was difficult to locate and required extra amounts of time to first understand an older system for organizing the information, then needing to dig through many different non-standardized documents to find it.

Another generally accepted benefit of PDM systems is their ability to make data available for reuse in other places besides the engineering department of a company. The small manufacturers in this sample also appear to be taking advantage of this feature in their own experiences. Generally they use their engineering design systems to share data with manufacturing and purchasing, which are traditional extensions of a PDM system (Ni, Lu, & Yarlagadda, 2006). While this is a very powerful aspect of PDM in larger enterprises, it may be less necessary or at least take different forms for smaller companies that have fewer employees and thus less organizational complexity. Again, a cost benefits analysis is probably a good idea for data sharing within an organization to see if the investment of time and money into automating data sharing within a company is worth the benefits.

Because these small manufacturers have relationships with multiple suppliers and customers, they happen to exchange data with these outside entities on a relatively frequent basis: most companies exchange data at least a few times a week, if not daily. This shows that these smaller manufacturers are in constant contact with their suppliers and customers, which can help to avoid

unplanned for costs and miscommunication errors. However, even though they are frequently exchanging data with outside entities, only a few use their design systems to interface directly with the customer or supplier. This may be due to the lack of integration between systems, or in some cases, the need simply isn't there to have an automated process to exchange data between companies. All interviewees during the first part of the study cited high costs associated with integrating suppliers into their system, and likewise some survey respondents cited high costs to maintain fully integrated systems with their customers. However, these small businesses are still operating as islands of data with manual, more closely scrutinized exchanges of data with outside companies.

The majority of the respondents to the survey state that their companies use neutral file formats frequently, or exclusively. This may especially be due to the fact that many 2D digital tools such as AutoCAD tend to use these types of "neutral" file formats as their standard file formats. However, with the high rate of exchange of data with outside entities, it is easy to see why the heavy use of neutral file formats is shown. While these neutral file formats are a good thing for the company to exchange data, they still lack much of the metadata that is more easily stored using native CAD formats, and thus smaller businesses may be losing out on the potential of a fully relational 3D modeling package since they are using neutral file formats to exchange data with customers and suppliers (Guk-heon, Duhwan, & Soonhung, 2002).

Although new research suggests that PDM implementation is most successful when it originates and is managed by the IT group in a larger corporation, most groups in the sample reported that their engineering design systems are managed by their engineering groups (Jackson, 2010). This may be due to the fact that specific groups of employees dedicated to IT, especially in companies with fewer than 50 people, are hard to come by. However, this may also be a disadvantage due to the fact that people who are not experts in system management and project management are in charge of such a business-critical system. It's important to mention here, too, that more than a few respondents

reported that their design systems were written and maintained internally, meaning their companies do not buy specially designed system software to handle engineering data, but instead they write their own using Microsoft Access or other easily available software development tools. This is an interesting phenomenon that would probably not be seen outside the small business arena. Perhaps due to this characteristic, most companies reported that they upgrade and maintain their systems either every year, or every 2-4 years, but very few reported doing this every 1-2 years. This differentiation may lie in the differences between companies supporting their own systems and those who are licensing systems from a software vendor. Companies maintaining their own systems would probably be able to make changes or improvements to the system more frequently because the software code is readily available, as opposed to commercial software solutions which could be more expensive and time consuming to update on a regular basis. Other studies have shown that proprietary enterprise resource planning software in particular can be beneficial for small and medium companies, and it's possible this phenomenon is also manifesting in similar situations for PDM type systems (Olsen & Sætre, 2007).

Contrary to popular belief, the small majority of respondents reported that their design system software including 3D/2D design tools, were not written by the same software vendor. This may be due to the relatively slow process of technology adoption in small manufacturers and a lack of system planning due to a piecemeal implementation of different business systems (Lee et al., 2000). It could also be because the engineering software industry has yet to produce a truly integrated, cohesive package of software that serves the needs of small and medium manufacturers without being too complicated or expensive.

How PDM systems change the business is one of the most important factors when trying to decipher how the usage of these types of systems have affected the companies that have adopted them, which is part of the research question for this study. The last three questions in the survey deal with how engineering design systems have affected concurrent engineering, clearly

defined design processes, and whether or not the system meets the expectations of the respondent. In a smaller company, each employee has a greater chance to interact with the engineering design system every day than might be seen in a larger corporation, and that level of familiarity may impact attitudes and impressions of the system itself. Most respondents felt that their design system had contributed to concurrent engineering, which is one of the main goals of PDM systems in general, but as an interviewee in the first part of the study pointed out, it's quite possible to use PDM systems in a manner that only further exacerbates the over-the-wall engineering problem. However, most respondents felt that their systems had made a moderate or higher contribution to concurrent engineering, showing that these small manufacturers are indeed using their systems as they were intended to be used. As far as restrictions posed by the system, most respondents agreed there were only slight restrictions or none at all. This was another issue that became apparent during the qualitative part of the study as something companies had to deal with on both a procedural and an organizational level. However, smaller manufacturers may not be experiencing as many problems in this area because their business processes are more flexible and thus once the initial period of acclimating to how the system functions is over, employees do not feel like the system has imposed as many restrictions on their processes as they may feel in a larger company. However, the majority of survey respondents felt their system met only some or many of their expectations of what it should be able to do, instead of all. While this is a positive sign for the software industry serving these smaller manufacturers, it also shows areas where improvement can be made, especially in the description and reality of what these systems are realistically capable of doing. However, it's possible that this level of satisfaction regarding expectations is no higher in larger corporations with enterprise-level PDM installations, and that must be taken into account when considering the results to this question in particular.

5.2.4. Variable Relationships Among Companies with Design Systems

One of the first questions to be asked on the survey for companies that reported having a design system was their personal involvement in the system at their companies. Most said they were very involved. The interesting part of this is that there appears to be a correlation between level of involvement and the effect the system has had on the time it takes to find information for design tasks. In general, as the respondent's level of involvement increases, the system appears to make finding information go more quickly. This is a positive trend, though also to be expected given that users who are proficient in using the system will generally feel it takes less time to complete tasks, including finding information, within the system. Although not statistically significant, there was also a slight correlation between the respondent's involvement level and expectations met. In general, as involvement increased, respondents felt the system was increasingly meeting their expectations. This is an important point to make, that for prospective companies looking to implement a PDM system, user involvement is key to ensure that expectations of the system are met. This can mean that future users get a better idea of what the system will realistically be capable of doing, and thus can lead to less dissatisfaction after implementation.

The timing of data entry into an engineering design system is also key to its success within the company. Most systems are built to become an integral part of the design process, and should be used as such to gain maximum potential. According to the data, there was a correlation approaching statistical significance between when companies are entering design data and to what extent they use automated workflows within their systems. It appears that as data entry happens earlier in the design process, workflow usage increases slightly. This is a good confirmation that these smaller businesses are using their systems as they were originally designed, though the low level of workflow usage shows that they could be missing out on some potential benefits from automating important processes. Along with workflow usage, there was also slightly less significant correlation between data entry timing and system upgrade frequency.

As data entry happens earlier, upgrades happen more frequently, which makes sense considering companies that are entering data into their systems at the beginning of the design process, and successfully integrating it throughout the entire design and manufacturing process, are more committed to investing in their system and staying competitive within their industry. It comes as no surprise that companies who are making the most use of their engineering design systems are also more frequently maintaining them.

The usage of workflows also has a correlation approaching significance with the level of sharing data that goes on within the business. As more and more data sharing within the business happens, workflows are more prevalent. This is understandable given that workflows are meant to automate data flow between people and groups within an organization, and by sharing engineering data with other parts of the business such as manufacturing, purchasing, and ordering, more tasks can be done automatically with lower risk of errors. For companies who are looking to adopt a PDM type of system, it may be worth a look to see if they are hoping to share engineering data with other parts of their business, and if so, workflows may be a particular feature any system they want to adopt should have.

Information retrieval and storage is another strong point of PDM and data management systems in general, and thus is an important element for small manufacturers to utilize when implementing their systems. According to survey respondents, there was a clear correlation between the effect the system had on time to find information and the effect on time it takes to complete a task after the engineering design system has been implemented. Generally, as time needed to find information decreased, time to complete tasks also decreased. This relationship is encouraging but also expected to an extent. As time needed to find information decreased, the level of data sharing within the business also increased. This is a positive sign, because often when companies of any size try to integrate systems with different purposes, such as a purchasing and orders system and an engineering design system, conflicts and difficulties can arise in

the integration. However, as data becomes easier to find within the engineering groups of these companies, they are also using this advantage to use the engineering data in other places around the business that may have otherwise not relied upon engineering at all. This helps integrate the different parts of the company while cutting down on time needed to find information.

Frequency of data exchange with outside entities was also a fascinating variable because it correlates with so many other variables, showing that this is an important factor for small manufacturers when they are looking to implement a PDM system. As the frequency of data exchange with suppliers and customers increases, respondents felt their engineering design systems increasingly contribute to concurrent engineering. This may be due to the fact that frequent data exchanges often means that engineering changes being communicated during these data exchanges are being put into the design systems constantly, and as a result concurrent engineering has become a necessity for the company to cope with so many changes. As frequency of data exchanges increase, survey respondents also felt that the restrictions placed on them by their design systems decreased. This was a very statistically significant correlation, and could mean a variety of different things. The correlation could be due to the fact that with more data exchanges, companies become more comfortable with the workings of their systems and therefore feel like they have more control over how the system works and can make it work better for them without having to change too many organizational processes around an inflexible system. The frequency of data exchange could also be affecting the perception of the design system by making respondents feel like without the system, the volume of data exchange would not be possible and thus makes the system an attractive tool to use to facilitate the exchange of data with outside entities. Also, as the frequency of data exchange increased, respondents felt that their expectations of the system's capabilities were increasingly being met. This may be due to the way software vendors are marketing their systems to small manufacturers, who often have to exchange data with a variety of outside entities that may or may not have similar systems to

theirs. However, it appears that data exchange capabilities were an expectation survey respondents had of their engineering design systems, and their systems are meeting those expectations fairly well.

Neutral file format usage also had an interesting significant correlation with which group within a business is in charge of the maintenance and upgrading of the engineering design system. As neutral file format usage increased, companies tended to have their system handled by the engineering group in their business. This makes sense, since neutral file formats are an aspect of engineering design and data exchange that most other parts of the business would have no real need for, but there's not necessary an obvious reason for why information technology groups within the business couldn't handle the design system too, even with extreme usage of neutral file formats. This correlation is probably due to the low occurrence of IT personnel in these small companies who make their money from engineering and manufacturing, and thus have more employees involved in those areas rather than straight IT.

System expectations being met correlated with both the levels of contribution to concurrent engineering and restrictions imposed by the system. In general, as contribution to concurrent engineering increased, the amount of expectations the design system met. This is probably due to the fact that often engineering design systems are marketed as increasing concurrent engineering and helping companies get away from over-the-wall engineering. Therefore, as systems do what they were designed to do and enable design and manufacturing engineers to work together throughout the design process from beginning to end, more and more expectations are met. Likewise, design systems are also marketed as being "customizable" and able to be configured around existing business processes. As a result, when design systems fulfill these requirements and the feeling of system restriction is lowered, expectations of what the system should be able to do also increase.

5.3. Conclusions

Given all the data found in this study, some conclusions can be made about common traits of small manufacturers who have implemented PDM-like systems. First of all, companies who have implemented PDM systems are generally happy with the way it is working for them. They feel their design systems have contributed to concurrent engineering, pose little or no restriction on their design method and their systems generally meet most expectations for what they should be able to do. Locating information is significantly faster, and the system makes doing a design task faster as well, although to a lesser extent. Most of the small manufacturers in the sample exchange data with outside suppliers and customers at least a few times per week, but this exchange is generally a manual process. The exchange does use neutral file formats relatively extensively, be they are neutral 3D or 2D file formats. Inside the business, companies are sharing data from their engineering design system with manufacturing systems and purchasing systems, but most do not use workflows as a way to automate the flow of data within the design system. They tend to upgrade their software either every year or every 2-4 years, most likely depending on the nature of their licensing agreement with the commercial software provider, or whether they have created their own homegrown system for managing engineering data. Most companies are entering data into their design systems as early as possible and using it throughout the design phase of their products.

Companies with more employees are more likely to have an engineering design system, and those companies using primarily digital formats to define design information are also more likely to have a system dedicated to managing this data. In general, respondents who are heavily involved in the day to day workings of their design systems are more satisfied with its effect on the business, perhaps because they are the most proficient users of the system. Decreased information querying times also correlates with the level of data sharing within the business, and with more sharing of data within the business,

workflow usage tends to increase. System satisfaction also tends to increase as the level of data exchange with outside entities increases, implying that companies that exchange data on a frequent basis are more likely to get the most use and satisfaction from a PDM-like system. The level of neutral file format usage also is related to which group within the company tends to maintain and manage the system – more neutral files typically mean the engineering groups within companies are responsible for the system. Companies also expect their systems to increase concurrent engineering, and feel that their expectations are met as restrictions imposed by the system decrease.

5.4. Recommendations for Small Manufacturers

Product lifecycle management is a concept that has been around for about 10 years in its current format (Stark, 2005). Larger corporations have been quicker to adopt its methodologies and approaches, due to the scale of their businesses and the level of cost savings they have been able to reap from implementing it. While the benefits of adopting PLM approaches to small manufacturers are more difficult to see, they exist. From the existing data, it appears that many small manufacturers haven't yet moved to a PLM mindset of how they run their businesses. PLM is not for every company out there, but it is increasingly becoming the language in which companies remain competitive (Miller, 2009). To remain competitive in their industries, small manufacturers will eventually need to adopt PLM ideas and implement them into their core business goals. From the data collected and analyzed in this study, it becomes clear that while manufacturers are heading in the right direction towards PLM and integrated PDM, they still have a long way to go. Especially judging from text answers to questions, these small businesses are still highly focused on processes rather than products, which is consistent with the existing literature (Schuh, Rozenfeld, Assmus, & Zancul, 2008). While that outlook may work presently, it could prove to be a disadvantage long term. 3D design definition is not necessary to implement PLM methodologies, but a mindset of focusing on

the product and managing products themselves rather than drawings and design specifications from customers or suppliers will probably help small manufacturers stay competitive in the future, as more and more of the industry moves to this type of design paradigm. This is even true of job shop type small manufacturers that do no design of their own; by reorganizing business philosophy to concentrate on the product they put out the door and attaching manufacturing data to that, rather than the other way around, they could potentially more easily improve processes and decrease unnecessary costs. By focusing on the product itself instead of the process involved to make it, small manufacturers can take their business to the next level by tracking quality and other statistics over time, and potentially improve both products and processes if they are dedicated to treating their products as the source and focus of all energy, rather than the processes involved in making them. One of the more attractive aspects of PLM to small manufacturers is that it's really not necessary in a smaller setting to hire consultants to come in and "implement PLM." The data suggests that small manufacturers tend to be more independent, and would rather keep their systems and work processes in-house. But because there are fewer people involved and relatively less data itself, PLM as a methodology can be adopted in-house by champions in the company that will drive change, instead of going outside of the business to hire consultants who will advise on what changes need to be made. This is a great advantage to small manufacturers because it means they can implement PLM methods at relatively little expense, and as long as there is buy-in from all stakeholders within the business, with relatively few obstacles.

As for small manufacturers that have not yet adopted engineering design systems of some sort, it is apparent from the study results that users of the system who are highly involved tend to be happier with the system. It is more likely to meet their expectations and make doing their jobs faster. It is a *cliché* to say that user buy-in at all levels is important, but the data shows that indeed there is a correlation between frequent users of the system and how it is received

in the organization. This is especially crucial for small businesses where a higher percentage of the employees will be interfacing with the system daily than may be the case in larger corporations.

Also important is the integration of the new system throughout the design process. The majority of small manufacturers are attempting to enter design data into their systems as early as possible in the product lifecycle, which is the intended use of these systems. Companies doing this are also more likely to take advantage of some of the inherent strengths a PDM system has to offer, workflow usage in particular. Those who implement a system that is mainly for archival purposes are missing the point when it concerns digital design and data management, whether it is 2D or 3D design. These systems were created and continue to gain popularity mostly because of the benefits they provide throughout the design process, and archival abilities were just an added benefit. They tend to help standardize processes and prevent rework downstream, but only if they are used as an integrated storage and communication tool throughout the design process.

Although most small manufacturers in the survey do not have automated methods for exchanging data with outside entities like suppliers and customers, it is important to note that as data exchange increases, general satisfaction with the system and its effectiveness in the organization tends to increase. This is especially important for small businesses looking to expand in the future. With the increase in data exchange, companies become happier and get more mileage from their design systems, which is a good rationale for investing the resources into implementing a PDM system or some other type of system that handles data. Automating this data exchange is not always necessary, but by getting a good system in place, finding the right data to send out and putting the received data in the correct place is made much easier by the presence of a well-implemented system. Furthermore, larger OEMs are looking for suppliers that are flexible and who are able to integrate with their own, larger, more robust systems. Having some kind of capability to automate data exchange could potentially

mean more revenue and business growth for smaller manufacturers, if they are willing to make these kinds of changes.

A well-implemented system will share data with other parts of the business. As part of a PDM adoption, other parts of the business absolutely must be taken into account during selection, planning, and installation. Most companies in the survey are using their design systems to share data with manufacturing and purchasing, which are good places to start in terms of business integration. However, choosing a system that is more expandable - beyond just engineering, manufacturing, and purchasing - may encourage future growth due to the added ability to track manufacturing and design performance over time and using that data to make decisions.

It's also important to point out that a commercial piece of software off the shelf is not always the best solution for small manufacturers. Depending on individual circumstances, homegrown software systems, while more expensive to maintain, can sometimes be enough to sustain a company for a number of years. Long term, however, commercial solutions are probably more viable because of the inherent benefit of having software experts constantly updating them and adding new features of which small manufacturers are able to take advantage. This is especially important as more and more software vendors are setting their sights on small manufacturing as the next area of growth in PLM and PDM. However, this increase in activity to better serve the small manufacturing market also makes for a complicated mess of different vendors offering different solutions, and sometimes the same solutions, under different names and a wide variety of levels of usefulness, problems, and integration capabilities. There does not appear to be a well organized and unbiased resource for small manufacturers to use if they are looking for information on adopting PLM and PDM technologies and theories. As opposed to the few larger software OEMs who generally cater to large enterprise level installations of their software, there are a lot of different and potentially confusing options for small manufacturers that, for companies who are not well educated in software systems, can spell trouble for companies without a

lot of resources to spare on failed installations or lack of expectations being met. This is a problem in the US specifically, where the larger software OEMs are attempting to take their enterprise level systems and cut them down to a more manageable size for small manufacturers, but still may be too cost prohibitive for the sample in this survey of less than 50 employees.

5.5. Recommendations For Future Research

The area of small and medium size manufacturer research in respect to PLM and data systems is relatively new because PLM is relatively new. However, this study only scratches the surface of how these smaller businesses are dealing with PDM, and further research must be done to get a more accurate and comprehensive picture of them and what lies ahead for them.

5.5.1. Procedural Recommendations

Good survey writing is truly an art. It is difficult to write an effective survey that will be sent to thousands of possible respondents that will accurately capture as much important information as possible. The researcher tried to err on the side of a shorter survey rather than a longer one, but because of the vast differences in the sample characteristics, the survey had to be written to be able to communicate with respondents who potentially had absolutely no knowledge on what they were being asked about – engineering design systems.

The first thing that the researcher would do different if given the chance to give the survey again, would be to add an introductory section to the survey that defined key terms and ensured that each respondent completely understood the terminology in each question. This would not necessarily remove all errors in survey responses due to vocabulary confusion, but would do more to ensure each respondent is talking about the same concepts. For example, the term “engineering design system” was used in place of “product data management system,” which was necessary because of the wide variety between different

companies. However, while on one hand the term's broadness is an advantage, it is also a potential liability because respondents were answering questions on their "engineering design system" which in reality could be very far from what a PDM system does. They could be talking about a simple document management system or mainframe type system that only tracks part numbers. While information for those companies is important too, it was difficult to tell the difference between these companies in the survey as it was given. If doing this study again, more questions would be asked about the specific nature of the system in question and its capabilities.

Beyond vocabulary, another issue that arose during the course of the study was the wording of the questions in the survey. When each question has 3-6 possible answers, it means that chi-square statistics are harder to accomplish because cell counts must be higher, meaning sample size must also be higher. Also, questions with multiple possible answers makes for even lower cell counts. This may have been accomplished with surveying an even larger sample of small manufacturers, but would have more easily been dealt with by rewording questions as a grid and asking each possible answer by rating on a Likert scale, such as:

Rate the functions your engineering design system is used for:

- General repository for data that is controlled (Rank 1-5)
- Versioning and access control (Rank 1-5)
- Product structure management (Rank 1-5)
- Engineering Change Management (Rank 1-5)
- Configuration management (Rank 1-5)
- Manufacturing information management (Rank 1-5)
- Other (specify)

By wording and designing questions in this manner, statistics could have been made easier and cell counts would have been higher, producing a more reliable probability value.

Given more time, the researcher would have created a different set of questions for companies reporting they did not have an engineering design system in place. These questions could ask why companies have not yet adopted a digital system of some sort, whether they'd looked at the prospect in the past but decided against doing so, and whether they believe a system would help or hurt their business and the reasoning behind those beliefs. This would have added more knowledge to reasoning behind not having a digital system.

5.5.2. General Research in this Area

There is an astonishing lack of research in the PLM arena focusing on small manufacturers in the United States, especially compared with the published research going on overseas in Europe and Asia. As mentioned earlier, PLM is a set of theories and methodologies on how to think of product development and it is applicable to almost any size company, but the literature seems to suggest that the only people interested in small manufacturers are companies looking to sell software to them. This is unfortunate given the proportion of industry that is being supported by smaller businesses, manufacturers in particular.

Also mentioned earlier is the inherent independent nature of these small manufacturers. Their leadership has a large influence on the daily activities of the business itself. Their employees may be resistant to change but their organizational change is typically more transformative rather than evolutionary, and there is more potential for a change to drastically affect the direction the business is going in. All these qualities make them ideal candidates for implementing PLM and PDM technologies and methods, but while there is a large variety in the businesses themselves, there is almost an equally large variety in the type of data management system they can choose to implement. This has its positives and negatives, but overall the variety makes it more difficult

for companies to choose the appropriate commercial software system for them, that meet their specific needs, simply because it is harder to find, and there is no centralized place to get unbiased information about most or all of the available options on the market.

Luckily, there are increasingly more robust solutions for small manufacturers that are maintained by well known software OEMs that provide functionality while making implementation and management simpler (Kevan, 2009). The challenge is convincing small manufacturers that these new systems will work as well or better than their existing systems, or convincing them they need these systems at all. A full two thirds of the surveyed sample in this study did not have a digital system, and demographically they do not look much different from companies that have implemented a digital system. However, those that have implemented a system are generally happy with it in its contributions to design processes and organizational communication. That implies there is a large segment of the small and medium manufacturer industry that could still benefit from some kind of digital design system, but for whatever reason, have not yet. More research in this area needs to be done to identify why certain companies have not yet adopted a system, and what sets them apart from their competitors that have.

5.6. Final Thoughts

In going through this study, the researcher came across an interesting revelation: small manufacturers are very enthusiastic about what they do. After the initial survey was sent out, the researcher received several emails from managers and owners of small businesses, curious about the results of this study. They all seemed genuinely interested in this topic because it's an issue they struggle with every day, but in some respects feel disenfranchised because they rarely have the resources to commit to an extremely robust system. They write their own systems, they do much of their data management manually, and they at times seem to be out of the loop of the ever advancing manufacturing

industry and all its leading edge technology. Alternatively, they feel that they are at the mercy of their larger OEM customers to conform to what the customer requests, often a huge investment in system infrastructure that is burdensome to them. But, they are also the same suppliers and small OEMs that keep enable larger OEMs to focus their manufacturing efforts on other things. At the federal and academic levels, there are many programs in place to help these small businesses thrive because they truly are one of the driving forces in the US economy. At the same time, there's an acute lack of academic research on these same businesses, about what they are currently doing, what they want to do in the future, and where they fit into the grander scheme of manufacturing economics. This study was mostly concerned with what they are currently doing to manage data in an increasingly digital world where forces beyond their control have started to make them do their design and manufacturing in new ways. But the real question is where this segment of the manufacturing industry is going in the future. How can we enable small manufacturers to step into the world of PLM and PDM in a way that is cost effective for them but will encourage growth and change while using their unique advantages to help them get ahead? These are questions that must be answered, and this study endeavored to be a part of those answers. Hopefully more research will be done in the future that will illuminate more traits of small manufacturers and find better solutions to help address their unique needs.

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APPENDICES

Appendix A. Contact & Consent Forms for Interview Participants

Interview Contact Text (Email)

Subject Line: Product Data Management Expertise Requested – University Research

My name is Karen Waldenmeyer, and I am a graduate student working on my master's thesis entitled: "The Small and Medium Enterprise's Perspective of Product Data Management," under the direction of Nathan Hartman at Purdue University (NHARTMAN@PURDUE.EDU, 765-496-6104). My research is focused on how small and medium manufacturers tend to view, use, and manage product data, usually using engineering design systems. The first phase of my project requires that I interview subject matter experts in product data management to get a better idea of questions to ask small businesses what their experiences have been with product data management and engineering design systems.

To accomplish this goal, I would love to be able to do a quick phone or onsite interview with you, as an expert in product data management and all its intricacies, to ask a few questions about your impressions of product data management systems and how they have affected your company. These interviews should take approximately 30 minutes – there are 5 questions in total. The interviews will be audio recorded, but all identifying information, both for you and for your company (and its products) will be destroyed to protect you. You may also opt for a copy of the final research report to be sent to you once complete.

All procedures and questions have been screened and approved by Purdue's Office of the Vice President for Research's Institutional Review Board for research involving human subjects.

Please contact me at 574-514-6229 or KWALDENM@PURDUE.EDU to set up an interview time before February 19th – I am extremely flexible and will accommodate your schedule accordingly.

Thank you for your time and I look forward to hearing from you soon!

Karen Waldenmeyer
Graduate & Research Assistant
Computer Graphics Technology, Knoy Hall
Purdue University, West Lafayette, IN
KWALDENM@PURDUE.EDU
(574) 514 - 6229

Phone / In Person Interview Script & Consent

My name is Karen Waldenmeyer, and I am a graduate student working on my master's thesis entitled: "The Small and Medium Enterprise's Perspective of Product Data Management." I work under the direction of Nathan Hartman, who is the primary investigator on this project. He may be contacted at the phone number 765-496-6104 or nhartman@purdue.edu if you have any questions. You may also call me at 574-514-6229 or email me at kwaldenm@purdue.edu if you have any questions.

I want to first thank you for your time and participation in this study. You have been asked to participate in a focused interview regarding engineering design systems in your workplace. Before we start I want to remind you of your rights as a participant:

Your participation is completely voluntary. You may end the interview at any time.

You are also free to refuse to answer any question.

This interview will be kept strictly confidential and the recordings will be destroyed after they have been transcribed.

The transcript of this interview will appear in my final master's thesis, but all personally identifiable information, including your employer's information, will be removed.

Thanks again for taking the time to speak with me today, and if you would like to receive a final report of the research findings for this study, please let me know and we will work out the details.

Appendix B. Interview Transcripts

Note: Below is the interview transcripts for the four qualitative interviews conducted during this study. Text that is indented and italicized are the researcher's words, while those that are in plain text are the words of the person being interviewed.

Interview 1

Okay. So, the first question. Answer however you want. What kind of pressures do you feel or do your customers in your context, whatever, whoever customers they may be? What kind of pressures do they exert on your part of the organization in regards to what software you are using for design and data management?

In our company as a whole, typically it's not that great. We're pretty free to choose to use what we want. However, on the program I'm currently on, it is in the contract exactly what software we will use, and at least for the PDM, that we will ensure that we will put our data, or the master CAD data, and the definition package. We're responsible for putting that into the customer's PDM. They even went so far as to tell us exactly what format the CAD system had to be. They were pretty new to the PDM so they didn't put a lot of pressure or any information in the contract on what the PDM had to be, but for the CAD system, the format, and even the extent of the parametric models, what we're expected to do in terms of it had to fully be parametric. It was written in the contract language, in the statement of work.

Wow.

Which was something very different than I think anyone has ever experienced before at our company. We went from one extreme which is, the customer lets us do whatever we want, they really don't care, at the end of the day we just have to give them sometimes just lists of information. I mean sometimes it's just an image, they don't even care if it's in an ASCII, or a format that is something you can bring in Excel, and manipulate in a digital environment. It could just be a printout. The contract we have now with the customer is very stringent. So, I've seen both extremes. Basically what we've seen is this customer is primarily responsible for the product. And as such, they're also under a lot of budget constraints. They want to try to make sure that everything is done as efficiently as possible. Because at the end of the contract, they're responsible for maintaining the definition. Maintaining the information. So because of that, they want to make sure that we've provided them with data in a format that they could

use. And that is, a possible future outcome for the industry as a whole because as we've been doing, this becomes apparent as you go forward that one of the major powers is having the data in a format that is compatible with your systems that you can easily use. And even though there's a lot of talk about XML and the power of it, at the end of the day, because of the differences there's still not a standard for any PDM or standard for industry. Well I won't say there's not a standard. There's not an industry standard that the industry is using

Right.

It becomes very important for information portability, that this could be a trend in a future. I could definitely see other industries, especially like automotive and stuff like that, definitely having more and more of this. But I would say it's a first for our industry from what I've seen.

Right, you could say that not only now are you just delivering the actual product to the customer but you have to deliver all of the data, or at least, a lot of the data that you generated while you were designing and making it to them as well. So, you know they have to use it, is that a fair estimation of that?

Oh yes. When we did a system engineering analysis of our program, it came to conclude, you know everything's about value added, and what is the customer paying for, what is he willing to pay for, what does he consider value added. Anything that he's not really paying for is not value added. So you have to pay attention to the value stream. And we had some expert system engineers come in and they looked at what the customer was doing, and what they were requiring, and we actually broke down our system engineering requirements such that the technical data package which is the government's term for the definition package, technical data package was considered not just not just a deliverable from a document standpoint, but a product. It was considered one of the products of the contract.

Mmmhmmmn.

And, as such, yes, it gets a lot more scrutiny and attention and we had a lot more system engineering oversight, and what would they call it? When you tear down the contract and the statement of works, you piece-part it, you know you piece-part all the requirements, you allocate them, to team, and you set measurable goals, and validations and verification matrices, I think we just call it shredding. We shredded it. And we actually allocated a lot of the technical data package requirements and our system engineering requirements because it was considered a product that the customer was paying for.

Right, okay.

That, that's kind of new too. A little different than what we've typically seen. And a lot of times the definition package, we've had to give it to the customer, being the government, and the Department of Defense, but it's more of a byproduct, kind of like a "Oh, when you're done, give us the drawings."

Yeah, yeah.

You know, "give us a report on what you've spent so far. Give us a report on the test results," No, this was very obvious it was a product they were paying for.

Right, much more formalized type of a process to get there and deliver that to them.

Yes, yes, and acceptance criteria for it.

Mmmmmhmmn. Okay, well I guess I'll move on to the next question. What would you say has been the biggest hurdle to successfully use the product data management system, during the design process?

Well, yeah, it all depends I guess on what are your expectations of the PDM.

Mmmhmmmn.

In the beginning, the expectation was "I just need some place, a central repository for my CAD models, my CAD files, and maybe to vault them so that once they're released no one can change them." Once we got past that, we started looking at additional information to store about the parts. And related to the parts, the product.

Mmmhmmmn.

I would say there were, let's see if I can stumble through them. One was, we get the PDM and it's more of an open architecture. From the OEM, the PDM software is kind of generic. So one of the big things is how do I adapt this more open architecture to my business processes, my business lexicon. You know, my business rules and procedures. And so that's a challenge in the fact that sometimes the PDM is not, doesn't match how you used to do business. You used to have business where we would write our own database from scratch, and it reflected exactly how we wanted to do business. Which, was of course a complete reflection on how we used to do the paper business. And all we did was take the paper information and regurgitate it into the mainframe computers into a database.

Right.

But hey, that's how we used to do business, and everything matches perfectly. When you get the PDMs that are OEM, and especially if you don't have a lot of pull on them, or even if you do, you may not have the time or resources. You have to look at what they're delivering. And they're trying to deliver a product that's good for most everybody. And you have to look at it, and you have to say "okay, here's how it works. Does it or does it not match how my business works, or how I've traditionally done business?" and then you have to ask the big question: "Do I change my processes to match the tool, or do I customize the tool to match my processes?" That is the biggest challenge that we've always done and it's been very interesting because I'm more, I'm more of the person that says "I'm going to adapt my processes to the tool." I don't want to spend the money, and I don't want to maintain the custom code. That's not the value stream. The customer doesn't care, a lot of times, exactly what your business process is, all they want is the product. So you have to look at what the OEM's PDM software come out and go "Okay, they gave me this, did they give me a solution?" Is it a viable solution, regardless of my processes. And if the answer's yes, you have to really ask yourself, "What's stopping me, from changing my processes to adapt to the tool?" And, it's also very anti-cultural. We've had a lot of top down, the managers saying, "Processes first, tools second." And it's kind of like, you don't understand. We're not inventing tools. We go out and we buy a tool. We've learned our lesson sometimes the hard way. Every time we go out and try to invent the tool ourselves, we find out that we're not good tool inventors.

(Laughs) Yeah.

We're good, we're good XXXXX product inventors. But we're not good tool inventors. You have to know your own limitations. And we're almost too arrogant, "Oh we'll hire someone to do it for us. No no no we can do that, it's not that hard, we do software for our XXXXX products, we can do software for this thing." And they just don't understand of course, when you do something for the product, there is so much attention to detail, oversight, quality. You're delivering a product to the customer. You have a lot of things in place to make sure that everything is done right. When we develop tools, it's more, in the back room. It's not the real product that you're delivering to the customer that has to be perfect. So everyone takes shortcuts. That's a lot of what materializes. So that's one, without a doubt, one of the big things with the PDM. Let's see what else. Another one is sometimes, the OEM, when they come out with the PDM they don't have, they haven't even thought of all the solutions needed. There's gaps in their product. And so, you have to try to fill that gap. And you can even do it, which would get to my next topic on this, you can either do it elegantly, or you can use a hammer and just, pound the square peg into the round hole. We'll just force it to work. You go back to the OEM vendor and you tell them about it, and maybe you'll get it in five years. Well I need a solution for the next five years, I can't wait for your upgrade. So there's a lot that I've encountered with that. It all boils down to the

next topic supporting the next topic, which is what you're trying to do with the PDM is single source of data, and you only enter the data once.

Mmmhmmn.

Then, it's automatically replicated and propagated in through your value stream. It's reused by your other systems or your other processes, and so when you do something upstream it has to be formatted in such a way that it'll work, not only for your needs, but also for everyone downstream. 'Cause you don't want to come and have to retype it in, or reformat it based on their needs. And of course, there's two things that happen with that, it's the same thing. You can either, if you want to try to keep it simple, then you have to try a lot of times what you do is you bring information upstream so that it's put in once up early, so that you don't have to have another schema or method to put it in again. And relate it to this part. It's better to have one form with two pieces of information, than two forms with one piece of information that have a relationship between them. It's much more complicated. So you're trying to say "how do I simplify this?" One of the things we do is we pull information upstream. So that once you put it in once, it gets reused. Two, you have to put the information in in a format that works downstream. So, sometimes you have to adapt formats and concepts and schemas that are being used downstream, upstream. An example for us has been our MRP system. The MRP system is a monster, it's huge. You're not gonna change it. Or at least you're not gonna change it anytime soon.

(Laughs) Yeah.

I mean, commercial's got an MRP system that costs billions of dollars. Or you can buy an MRP system from SAP, and SAP's gonna tell you to go pound sand if you ask them to change their schema. And so you have to say well, that, the MRP system, has to work this way. So now I've got two choices. I can either, adapt my processes and my formats upstream to match my MRP system, or, I can write an application that translates it from one format to another. Like an XML stylesheet or something like that. You know, here's the input, reformat it, different output. And, that is usually one of our last resorts, is to do that. And that's not that bad, because it's kind of a black box, it's in the background, and it's running. It's just sending the information from one system to another. The other thing, and the last thing you want to do is customize the schema, put in homegrown, your own application, your own software customizations. We did that on one of our programs, and everything's fine until, oh, we have to upgrade now. And that's the problem, it looks great and it's fun up front and you're doing all this great stuff but the cost of maintaining is so tough. Right? So, because of that, you have to always try to go back to what can I use out of the box, off the shelf, trying to do that. So in our environment, we're a company run by engineers, engineers love to make it better, right?

Yeah.

Better is the enemy, better is the enemy of good enough. And that's the battle we're always fighting, I think. A lot of engineers want it to be better better better, why? Because they can. They can make it better. But what's the cost of better, what's the cost of maintaining it? So I would say, those are definitely my inputs on that topic.

That seems to cover it. I worded the question as having the biggest the hurdle, but I know there are many and so, obviously it sounds like there are a lot. At least from my experience it sounds very universal; the stuff you're talking about is the stuff I've dealt with in my work with other companies too. The process vs. the software, and how much functionality can we get out of the box, and trying to maintain our own code is a pain. It's just gonna cause us more heartache later on even though it seems like the best bandaid for right now. So yeah, that sounds like a good thing. So I guess, on to the next one here, what have you felt has been the best and worst effects of using that PDM system in the design process?

Let's do best first, it's the fun one. At the end of the day, you're trying to put the information in once and then it just flows, so you get so much more productive. The productive enhancements are fantastic. We see it because one of the things that we do, is we bring the work up upstream. You know, and put everything in at once. Instead of different people putting it in at different times. Like I said, we try to have the one form. And that's not how things used to do, you used to be very siloed, right? Designing, the strength engineer would do his thing, and he'd tell the design engineer this and the design engineer would do his thing, and then he'd be done and he'd throw it over the wall, and then the ME do his thing, and then he'd throw over the wall. So, now with integrated product teams, concurrent engineering, and well, we have model based definition, we have the concept of the BTP, build to/buy to packages. What we're trying to do is we're trying to bring all that information that everyone did scattered throughout the process, into a single package and that's what we call the build to/buy to package, BTP. And within that single package, we're trying to put a lot more information than we traditionally did. So now, the definition includes the manufacturing configuration as well as the engineering configuration. It may include information for tooling, it'll include information for strength, so we're trying to put a lot more information into that single package. And once you do that it can so flow. That changed our processes but it's also been very good nominally because what's happened is the people downstream don't have to redo work, we have less people downstream. We can do a lot more with manufacturing engineers now. They're not redoing work. Also what it does is it brings everyone together to get it right the first time. So it really encourages, it almost mandates concurrent engineering. It's so powerful that our organization reflects the same thing so well if I've got a strength analyst and a design engineer and a manufacturing engineer and a

tooling engineer, and we actually pull in the buyer now. All trying to put information in up front, and they're all working together on the single product. Well wow, why don't we have them all report to the same manager?

Right.

So we've got IPTs, I don't like the word IPTs, it's so abused. I came call it IPZ, integrated product zone. Just so I could be in IT because IPTs are supposed to be around a product but the problem is, is people would say "well the product is the airplane." So I'll have the design group for the airplane, and then I'll have the strength group for the airplane, and then I'll have the manufacturing group for the airplane. Well that's not any different than how we did business thirty, forty years ago! So what we're trying to do now is say "well I'm going to have a group that's in charge of the flap." I'm gonna have a group that's in charge of the outer wing panel. And, because they're all kind of co-equals in owning the definition, within the PDM they're in the same group. They'll also sometimes have write access to each others' data. And that's reflected in the PDM. The PDM is allowing, encouraging, enabling - because it's more efficient - concurrent engineering. Because not doing it is a lot more difficult than the PDM. Easy way out, keep the PDM simple, you guys work together up front to figure it out. That's one kind of strange thing about the PDM. And that was all about trying to get reuse, get the data in correctly at once and use the fallouts from it. The other thing for us, without a doubt, is the speed of information querying and recovery. Once you start going down the road where you start treating the information as database objects, database information, getting information out of there is just phenomenally fast. And you just keep on thinking, how can I deconstruct, decompose, more and more of this file-based information into object based information. So, an example would be, you know a long time ago we would have drawings. Which would be in a file. And then we would put the parts list and the notes list on the face of the drawing. And it would just be text. And that was very typical 20 years ago. You're pretty good if you could have a separate parts system, separate notes list. Some of the major aerospace companies, or the major portions of the aerospace companies would have mainframes with the notes system, the parts system, configuration control and that. But some of the smaller companies, or older divisions, wouldn't, or older products wouldn't. So now you wanna go find this part, somewhere, where is it used? You have to scan drawings now. It's not a list, there's not a database, you have to scan drawings. Or there's this material being used. Where is this material used on all your parts? You'd have to get an engineer to go look at all the drawings. One at a time. Or you'd have this note, and this note was invoking this old process spec, or old material, like old sealant. Or we wanna know all the parts that are using this old material because it's obsolete, we need to go fix it. We need to go change it. Well, it was only 10 years ago where, yeah, we have parts lists of objects but we had notes lists as text files. They were text files stored within the PDM. So when we had to go find notes we'd actually have to export all the files to native and

then run a query for the text files looking through the notes. "Oh, here, this note is in this file, this file is named this which of course the name matches the part number," and there you go. But that was a lot of work, we had to get the DBA and the administrator to run that, to run jobs to export all that stuff, and we had to get computer guys who know how to query the files, and search. Now, all of our notes are objects, all of our materials are objects, so you can search for the text of the note. In 15 seconds, through 20,000 parts and probably 2,000 notes, and you instance some of those notes. In 15 seconds, you've found whatever text you want. Then you can query and in 10 seconds you can find all the parts that are using that note. So the querying capability now is fantastic, and it's gone to the point now where we have this extra information on there. Is it a buy, is it a make, who's the supplier that's making it? So now anyone in the entire IPT has huge amount of information at their fingertips in seconds. While before, oh, well here's this part but who's making it? Well I don't know, we have to find the buyer, is the buyer in? No, he's on vacation today. Well who else knows? Where is that in the system? Is there another buyer, okay he's gotta log in to a separate system and go find it. And so as you get more and more information into the single depository and that single source of data is common and the people know how to use it, you're able to leverage and get more and more information quickly and easily. So visibility, and quickness and access to information is tremendous. It was funny, I had some guys come over to me and they were asking me "Yeah we need a list of all the product part numbers." And I said well there's about 5500 of those. And they're like, "how do you know that?"

(Laughs)

I says, "it's a simple query! It'll write the whole list for you, duh!" And it tells you at the very beginning, "it found this many entries." What is my search criteria? And I did this search, and I got em, and it was like 5487. And I say, I remember the round up number. And it changes, it 'll change one or two every day, as we figure out we need a new part number and we need a release or something. I was talking to some guys over in another part of our company who's doing things more the old-school, and where they're still maintaining the mainframe for the notes.

Wow.

They have to submit a request to a programmer to write the query, and it usually takes a week. And what happens is after the query's done they give them the results, and he looks and says "uh oh, either I didn't specify the query exact enough, or he misinterpreted my query. So usually it takes at least 2 weeks to get the information that today, I can get you that information or anyone who knows how to query the object-based database which is relatively simple, any engineer can get that information, maybe 30 seconds. So 2 weeks or 30 seconds.

Right, even if it's a whole lot of information, it might take 5 minutes, at the very most.

At the very most! And usually for us it's five minutes, not because it took you that long the run the query, it's because you did the same thing and you ran the query once and go "why did I get 10,000 parts? Oh shoot I did my filter wrong." Or you find out that you're up against the wall and there is no way to segregate the data, and you're gonna have to say, "Oh, okay, I'm gonna have to take this into Excel and I'm gonna have to parse this out a little bit because I need to find this key word here, and I've got to go find this key word and segregate it out based on this key word that's based in this field." That's a lot more difficult to do, in a database with out of the box user interface. You can get someone to write a query for it, but I'll just bring it into Excel, and then I'll write my own little query in Excel and get that done. I would say, that's the second one. The third one is discipline. When I talk about business rules, I mean engineers give attention to detail to what they consider important and what they consider important is the definition of the part.

Right.

I mean they will have the exact location of that hole within a tenth of a thousandth and they'll figure out the tolerance for it and all that, but they'll give it the wrong description. Or they'll give it the wrong CAGE code. Or they'll give it the wrong stock size. They make these silly errors, because one, they don't think they're important, to what they consider important which is the definition of the part. But all this other stuff is used downstream by everybody to filter and propagate it. So like any database, the PDM is a database, you're able to put templates and filters and checks and rules that say hey, you have to fill this out. Oh, and here's a list of values, you have to pick one of these. And it keeps you from fat fingering the information so that everything is consistent to help with your queries. Like any database, that's the typical benefit. So, I think those are the big benefits. I can't think of anything right now that's not uncommon. There's the workflow, gotta admit the digital signatures are really nice.

Yeah, yeah!

You don't have to walk around and ask people to sign stuff, so now you have the workflows in the digital, but now we're getting more typical I think. I can do workflows with document systems. PDM is just reflecting what other document systems can do as well.

So, what would you say the negative effects have been?

The negative effect is the one thing I can come up with, there's not that many. It is a straightjacket. If you have an exception to the rule, it's very difficult to handle. You have a square peg, and all I've got is round holes in the database. How do I make it fit? And you're sitting there going "Oh my god, this is an exception, I'm gonna have to change the database schema, I'm gonna have to change the rules, what is the impact downstream? I've got an exception here. How do I handle this?" Before, since there was so much manual stuff in place, you could send an email out, or you can send a memo out, or change a piece of paper that said "If you see a part with THIS label on it, then handle it this way instead" and the people would read the piece of paper and say "Oh, I'm supposed to do this differently" We used to have on our engineering orders, a section of the EO just for stuff like that. Hey, this one needs to be handled differently. We still have it, but it's more standard now. There aren't as many exceptions but we used to have a section, and it was just you talking to people downstream saying, "hey, this is different. This is why it's different. Handle it differently this way." So, and people would get it and read it, but with the automated process it's a lot harder to do that. We haven't had it yet, but that would be interesting, you almost need a flag, that says "I am different, I have to go through a manual process instead of an automated process" we haven't had that yet, because every time I've seen that I've gone "Do I HAVE to make a square hole?" And it happens all the time. It's because the discipline of the PDM, to get it automated, is the information up front has to match what you're gonna use downstream. And it's always interesting to find how difficult that is with the design. Flexible parts, parts that get modified after they're assembled on the aircraft. Parts that get put on the aircraft and then taken back off. Two parts that occupy the same part of the aircraft, but they're different mission systems. I have a pylon – sometimes I have a pylon, sometimes I don't. We have this where sometimes I have a fairing, and sometimes I have a piece of mission systems in place of that fairing. Well, I have two parts taking the same space. How does that work? Alternate configurations. Effectivity, changes, variance, options, arrangements, how do you handle the fact that I could have an actuator, a single part number actuator, that in one location I install it extended, but in another position I retract it. It's the same part number, but it looks differently in both places! So it has to be different, yet it has to be the same.

So how have you guys been able to handle all those exceptions? In your experience?

Creatively using out of the box capability. I always explain it to people where, I'm gonna give you a hammer. Here's a hammer. What do you do with a hammer? Well you hammer nails! But can you only hammer nails with a hammer? Oh, no, I could bang pieces of wood, I can pull nails out, I can bash holes in walls, I can bend a pipe over, I can flatten a pipe, I can bend sheet metal, pound sheet metal into shape. So what happens is you look at the PDM as a tool. The OEM comes out and says, hey! This tool, or these features of the PDM, these features are

little sub-tools. It's supposed to solve this problem. This is how it works. And you have to say "well that's one use, you have to keep in your mind, that's one use for that tool. That might solve another problem." That's how I've been solving a lot of it is trying to, I don't want to use new software. Again, if your back's against the wall, then we'll write our own custom code. But we always try to go, what are some of the ways I can use out of the box, ways that the OEM never intended, but they gave me a tool and I'm gonna use that tool to serve my purpose. One of these days it'd be very interesting to get with these people and find out, I've got these different geometric problems, these definition problems. How do you solve it in your PDM? Sometimes the way I've seen other places solve it, is they took a manual approach. Well, we did something different but now somewhere down the stream, we either have to have a computer program running that recognizes that difference and makes it the same for the downstream processes, or, we print it out and the person types it back in and when he types it he knows how he's supposed to type it back in differently. We had this one area where we documented their release process and it was hilarious. They had to print out information twice. And retype it into another system.

So when they print out that stuff, do they immediately then go put it into a different system, or do they file it away somewhere so that 3 months down the line, at some other point in the process it needs to be changed then, or is it immediate?

No, usually they print it out and type it in another system and then they throw it away. Because no one paid the money to link the systems together, with the input/output, with the formatting. Or no one spent the money to do it. And like I said before, this is the back room stuff, it's not the value added stuff. It's not what the customer's paying for, it's not what has all the attention. The attention is on, what's the most efficient way I can produce that product and get it out the factory door because every time it goes out the factory door, someone puts money in my hand. Goes out the door, money in my hand, wow! I put more out the door I get more money in my hand, I put out faster I get more money in my hand, I make them cheaper, I get to keep more of the money in my hand. That's where all the efficiency is. The back office operation doesn't get the attention, and that's one of the things I find happens all the time is, the PDM is not considered the value-added element in a product oriented company. It's there to support the manufacture of the product. One of the things is that classic chart, who casts the largest shadow? The engineer's this tiny little guy, manufacturing is a big manufacturing building, you look at it from cost, and engineering, nonrecurring is only 5 percent of the cost. But who influences of the cost of the product the most? Who has the most control over the cost of the product? That's where people have to start learning that PDM is the beginning of the value stream. Or it's the beginning of the information. It is the source of everything of the product. If you get it right, and you get it well up front, everything else downstream flows a lot easier. Getting that into a company that is difficult. I mean, you are so

removed from putting the product out the door to getting money in your hand, that's very difficult for people to understand, that that thing that is so far removed from the product, for the actual money transaction casts a huge influence on the cost and the schedule and all that that you're doing to get that product out the door.

I would also imagine that knowing PDM systems, since they manage so many different products, it's hard to really put a quantifiable amount of money on how much that PDM system really affects each product. You have someone down the stream who wants to put a number on how much of our PDM system goes into the cost of this product, I would imagine it's very hard to quantify, especially for a larger company with a lot of different products with a decent amount of variance.

Yeah, well everyone always says "well we need a business case." And I'd be like, "Nobody has ever written a business case to justify email. No one has ever made a business case to justify the usage of the internet." Some things are intuitively obvious. And you can't actually justify it, or it's very difficult to justify because you're talking about a major exercise in gathering data and doing experiments and those are the things that the company does not measure. What does a company that produces a product measure? They measure how much it costs to produce the product, because that's what the business is oriented around. They don't measure how much does it cost to define the product, how much does it cost to analyze the product, how much does it cost to change the definition of the product. It's not something that get measured.

And even if they tried to measure, it's really difficult to measure. I'm seeing people try to say well, "the amount of the time the person used of their day to go through and run those analysis models," then it becomes a labor connected cost. You have to try to factor in the software costs and the maintenance costs for that software. It just gets out of control really fast from my personal observations.

Yeah, the one that I always like, is because it always comes back about every, 7-8 year cycle. Is everyone gets up in arms about quality. Quality! And it's a good thing in the product, but then someone says, "Well we measure quality, let's measure the quality of the engineering." Oh well, that's a very good question! How do you measure the quality of the engineering? Now, when you look at the quality of a product, what are you measuring? You're measuring what is the actual versus what was the requirement. Did it or did it not meet the requirements. So if you didn't meet the requirements, you have a quality failure. If you met the requirement of the product, you have success. Well where's the requirement of the product, that's from engineering. So now you're back in engineering, and you're saying "well how do you know you have a good or bad engineering?" There's two things, with quality. There's chances of error, and then

there is what is the requirement? What are you measuring to? You look at engineering and you say, "what are the chances of error?" And you start looking at it, where could I put the corner for that part? A billion possible places! There's no way to measure it because you're not measuring it to something. Engineers are like god, they create, boom, it is, I think, therefore it is. I imagined it, and I created it, therefore it is, that's all there is to it. It IS! It's kind of interesting when we get into things, engineers will look at it, a piece of engineering, and we get a tag and we look at something, the engineer says, "Oh the engineering's wrong. Oh shoot." I have to try to explain to people[engineers], and they'll read the tag and they'll go, "I don't understand this tag. It didn't say the engineering's wrong, it said this, this this this." I say, "Well you have to understand, everyone downstream, the engineering cannot be wrong. The engineering IS." And therefore the part could not be made to the engineering. Like one thing came back and said, "We do not have the equipment nor do we think the equipment exists to produce the configuration that you have defined." And the engineer's going "What in the world, why would they say, why wouldn't they just say the engineering's wrong?" Because it can't be wrong! So, it's always interesting as a good example of how do you measure that which you have nothing to measure it against. That's innovation.

Well, I guess we'll get on to the next one, I don't know how applicable this will be for you, since it sounds like you use and affect the PDM system at XXXXX pretty much every day, but what has been the biggest effect of these more modern PDM systems on what you're doing every day at work?

(Laughs)

(Laughing) Maybe it's a better question to frame it as, how has it changed in more recent times versus, how you used to do it?

That IS my job! How has it changed... well because of the impact of course it's changed a lot more. It's a lot more about integration. Originally, you would kind of have a PDM group and they would manage it and set the rules and their emphasis tended to be more about, we talk about archiving the data, backing up the data, and data integrity. Now it's more about propagating the data, linking the data, making sure all the data is formatted properly and usable downstream. Making sure it's available to everybody. Problems with the infrastructure availability, more training, now that you're going beyond engineers, you're going to suppliers, you're going to customers, now you spend more time documenting and training people on how to use it instead of before, "it was all engineers, they're real smart, they'll figure this out," well sometimes they can hack their way through it. Maybe it's because I'm more at like, the bleeding edge of this. The PDMs used to be dominated by IT people. Database people, IT programmers, and I'm a design background. I've got our PDM, and it's no longer being thought

of as an IT tool, it's being thought of more as what I call a definition tool. It's starting to lose its IT sheer domination, and becoming more looked upon as a tool of integration across multiple disciplines. It's kind of interesting when you look at what the designer does, a designer has to weigh everyone else's inputs, and I sometimes wonder if I fall into this role because the design background is about managing conflicting interests. As the PDM grows, you're doing the same thing. You're managing conflicting interests. I'm starting to see it happen more across the company, where it's not just IT anymore, systems engineering, design engineering, is becoming a larger influence on the PDM than it was originally. So I'd say who's responsible for it is changing, and if you look at it from days before, 15 years ago, PDM was kind of just there, working in the background, you'd spend a little bit of time filling in the data, and that was about it. You spent most of your time in the CAD. Now, the design engineers will tell you, I probably almost go 40/60, I spend 40% of my time in the PDM, 60% of my time in the CAD. Either I'm spending 40% in the PDM because I'm documenting the notes very accurately, the materials, the data, formatting it for all of the information that has to propagate to the suppliers, or I'm in the PDM retrieving information. Where is it in the workflow process, what supplier has it, what are all the parts that are affected? They're querying the database and spending more time in there than they used to. You ask the design engineers, what their differences have been, they'll say they're spending a lot more time working in the PDM.

Makes you wonder if they view that as a positive thing or a negative thing, I don't know.

It depends, if they're putting the data in they hate it, if they're retrieving the data out, they love it. It was interesting, I'm starting to do something with XXXXX as well, like with Purdue. I graduated from XXXXX, and it was interesting I was talking to one of the professors and they were saying it's just like what you guys are doing at Purdue, the classes and the experiences and what they're developing and learning is much more relevant to industry than when I was originally there. When I originally went to college, it was more like reading, writing, math. It was the basics, the real fundamentals, and everything. For now, I was helping my daughter with calculus the other day, and I'm looking at it and her boyfriend's over and he's saying, "Oh yeah he'll know this!" I haven't looked at this stuff in 25 years! This is all done by the computer now. The computer does all this in the background. We're more worried about getting the information in there, the relationships, the geometry, I don't care what the mathematical model is now on how it does calculates the volume of a lofted surface. It just does it. What I'm worried about is, does it meet the requirements, am I maximizing or minimizing, so the hardcore mathematics, no one uses it. The people who use it are the .001% of the engineers who program the software.

Yeah, yeah, the people who are writing the kernel stuff.

Yes, exactly. Everyone else just uses it. So I was saying, one of the best things that I took to help me today was learning software programming. We started learning that when I was in high school, and then I took it in college and I took it after college. Because at the end of the day, we're surrounded by computers. And you have to understand the logic, the processing of the computer, even if it's as rudimentary as basic programming, you've just got to know that there is no easy button, no magic button, someone's got to write all these lines, someone has to think of all the rules, someone has to do the logic and you have to understand that. And every engineer needs to know that. It was interesting, I was talking to some guys today. At the end of the day, an engineer retrieves information, processes the information, and then stores the information. That's what an engineer does. He doesn't go out and build anything. He is just processing information. Retrieve information, reformat the information to obtain more knowledge, to add knowledge, and then put the information and hopefully knowledge back into a system. So the other thing I said, it wasn't until I got working in '89 that we had all this information, and we were getting buried here so we set up our own database for some things. And that's my first contact with a database, was not in college. It was after college. The other thing I told them was, all engineers should know the basics of databases now.

Yes, it's funny you say that, because, I've been TAing the PDM course at Purdue, this is the second year, and most of our students are engineers or designers. Either they know a lot about the math, or they don't know a whole lot about the math, they're just end users like we are. To stand in front of them, and ask them, "So do you know how a relational database works? Do you realize that this is a table, and there are fields, and there are different relationships, and this is the very basics. You've got objects and you have to associate difference pieces of data and you need to account the filetypes and the amount of space all that's gonna take up." They have no idea, neither the engineers nor a lot of the design students that I teach. It's really difficult to try to give them an idea, when we got into Teamcenter, and we're handling objects, those are objects inside a database, and we attach a CAD file to it, we attach a note to it, we're managing those fields. We're not managing the product structure as you look at it inside the CAD system. And they don't get that, it's really difficult, and you can't give them a crash course in, the essentials of databases in a half hour. It's really difficult, so I definitely understand what you're talking about.

I would remember in, it was probably like '95, so 15 years ago. I remember I was working, in '89 I was working with some databases, elementary stuff. Just really elementary stuff, but learning it, understanding it. It was like in '95 it really clicked in my head, maybe it was '93, it was with UG came out with solids. And I was working with the solids. And I realized, wait a minute, all the data in Unigraphics is a database. It's all a database, because I got into it, the solids were corrupting

or something like that and I remember I had to get in with UGS and talk to them about stuff. We were looking at the error logs. I'm looking at it and I'm going, "Oh my god, it's a key! It's a key ID! It's a database!" The light went off. And then you look at PATRAN. It's a database. PDM, it's a database. Hey guys, Outlook, your email, it's a database! Google, it's a database. I was just telling a guy today, one of the things about Microsoft, is the operating system isn't made to be a database. Someone explain to me how it takes me longer to find a file on my hard drive than it is to find information on the entire internet from Google. That's ridiculous. That's one of the things that has to be taught and right now we have kind of older engineers. We have a lot of older engineers. We're not full of young engineers, because aerospace is kind of tight, so a lot of the engineers went off to internet companies and stuff like that, so aerospace has got a lack of people of a certain age, the younger generation. The number of times I have to try to explain to people, you can't really do a "copy." Like a Xerox copy in the database. It won't allow it. All you're doing is adding another pointer. It's like imagine you had Microsoft Windows, and you have all your files, but I took all those files and hid them. All I gave you were shortcuts. All you see is shortcuts. That's how I try to explain people the PDM. All you see are shortcuts in the PDM, you don't see the actual files, it's all shortcuts. Everything. You don't even see the real folder, it's a shortcut. Then they start getting it. I was hoping that the younger generation coming up would understand it a lot better and I hope so, and maybe I can have some influence, maybe you can help too. I really think undergraduate curriculum has to have one course on databases.

Yeah, in my curriculum I went through as an undergrad in computer graphics, right when I started, about 6 years ago, before I had started, they had 4 different tracks and once you started as sophomore in one of these tracks, it was very regimented. You have to take this class, this class, this class. When I started, they kind of made it more of a free for all and you got to pick more and you didn't really have as many required classes. Well, the virtual product integration track, before I started, had a database class that was required. At the time it was a web database class but basically, you learn SQL Server, and you've got to basically write the database, and then you just interface to it using the web browser rather than your traditional type database interface. I took that class. But most of my classmates didn't. So when I was asked to figure out installing Teamcenter here, I wasn't completely lost. At the time I had had a little bit of database experience, but not a whole lot. I can't count on the hand the amount of times I've had to stand up in front of lab and explain the pointer thing. Yeah, when you go into My Navigator, and you see all those links, those are actually just links. You can copy them, you can delete them, you're not getting rid of anything, you're just getting rid of pointers and shortcuts. They seem to get it, but I'm still afraid they don't get it as much as I personally wish they would. It might just be a matter of time and getting these concepts in the hands of engineering students. I think - I

don't know how much on the cutting edge of getting PDM into colleges Purdue is - but I've only heard of it at a few other schools around the country, around the world. To give our engineers that experience I think is a good thing, but it's not as widespread as it needs to be.

It does, the schools have to understand, at the end of the day, when the engineer comes out in industry, everything he's doing, retrieving information, processing information, storing the information. Well two of those are in a database. You've got to understand the basics. You can do the SQL programming, and I don't even know that. I don't know SQL or any of that. I've spent time with databases, making the basic structure, Access, and some other ones. But just that, has set me so far ahead. It was funny, I just got an iPod. Finally buried my Palm, and I got an iPod, and the first piece of software I bought was a database, for the iPod. It was like "I want to store my information on there and the way I want my information, no one has written an app for." And I'm not a programmer, I'm not gonna write my own app, but you give me a database, and I know how to put the information, you want information at your fingertips. What is information storage? It's a database.

Well, okay, I guess I'll get on to the next one and we've kind of touched on it a little bit, your overall impression of product data management systems, but would you say it's a positive or negative effect for the company, or the industry?

There's no doubt the positive effect. The engineers grumble because it's very strict. There's no doubt about that. But when you look at the fact the business is more efficient, there can be no denying that you are accomplishing more with fewer resources. You're making more money or, you're staying competitive. If your competitor has the PDM and you don't, he's gonna put you out of business unless you get a PDM because it brings with it an increase in efficiency. People have to stop thinking of it as just a product vault. It is source of distribution, a source of propagation. Once you put you put it in there right, you can automatically or seamlessly distribute it, and propagate it, distribute it to your suppliers, distribute it to your customer, or propagate it through your other systems. Without that, you can't. You're just asking for people to retype stuff in over and over again, you get errors, typos, transcription errors, misinterpretation, it's slower, it takes more people, it's almost not a question of if, it's a question of when. Industry has to do it. Of course the bigger the company, the bigger the product, the more imperative it is. If you're just a product company doing nail clippers, you probably don't need it. Just our product, we're running over 135000 parts, now in the product. How do you manage 135000 parts in a product, and that's for shipment 1. And for shipment 2, it could be the same number, but they could be different. Or, it could be a few extra, or a few less. How do you know? How do you manage all that information? It's a monster. We model tack rivets for plate nuts. We don't just model fasteners. Why are we doing that? Because if I

can model that tack rivet exactly like it's supposed to be, not just the part number, not just the part family, the actual length of the rivet. I've got the actual part number modeled, that now will automatically, once I model it in the CAD, now it's in the PDM, now it's in my VR environment, now it gets consumed into my MBOM, now it automatically goes to my MRP system, now it automatically goes to my purchasing system. And all the engineer had to do was put it in the CAD system.

Right. So would you say, I don't know how much work you get to do with your suppliers, but do you guys tend to mandate what kinds of system they're using to manage the data that they then pass on to you?

When we give them data, we're actually the complete opposite, it depends. Like commercial, they tend to say to the suppliers, "We will give you and only give you, say CATIA 5 files, that's it. If you want to be a supplier for us, you have to use CATIA 5." So we're more of what I want to call the Adobe syndrome. I'll author it in Word, I'll author it in WordPerfect, whatever you want. Then we'll translate it into a format that is more universal. So for our CAD systems, all that information we translate into STEP and IGES and Parasolid. And then we make the STEP, the IGES, and the Parasolid available to our supplier, we call it the TD, the translation dataset, it's a zipped dataset. And in that is actually 5 files. There's an IGES file, a STEP file, a Parasolid file, the reformatted UG file – we send that through some processing

Right, to take out, I would imagine, important stuff, right?

Yeah, yeah, what do is we kind of filter out the stuff we don't want the supplier to see. They don't need to have the construction geometry. We have the processed part file, and then we put in the log file that is the log of the software that processed it. So we have a record of exactly what happened. And all that gets zipped up and put there. And now the supplier, it's his choice which format he wants to use. Now, what we do do, and I'm not intimately familiar with it, but our supplier quality goes out and audits the suppliers and they have to have a DPD? Digital process definition? It could be something else, but anyway, they go out and they verify that the suppliers know how to configuration control the digital data. So if you download a file from us, you have to show me how you - and we have a checklist of what you're required to do - how do you store, and vault it so that no one can change it. How do you make sure there's only one source, that you don't have unauthorized copies? How do you know that you have the latest copy? And that someone didn't copy an old copy, and you downloaded a newer version and they're still working to the older version. We've had this happen before, where we've given the supplier the latest revision, but the NC programmer still programmed to the old revision, and we got the old part submitted to us at first article. Here's the part! And we're looking at it going, "Uh, that's the one from 6 months ago. We changed that. We wanted the new one."

And everyone knew it in the entire system except the guy that retrieved the file, he didn't go back to the master source, he went to the copy that was on his desktop, on his local computer. No, what is your processes to make sure that when people go to the file they're always going to the master. So we don't dictate any software, but we do dictate that you have to have processes and procedures, and it could be software to help you, in place to make sure that you're using single source of product data. So that's our supplier quality does that. On the flip side, on our program, the customer not only does the customer pay for the engineering definition, the models, and analysis, but he also pays for the tooling. And it's all the tooling, and that's got everything shocked.

Yeah, that's a lot!

Because most people are like, "Oh you mean the jigs!" No, not just the jigs, we're talking about the drill template, the form block for a sheet metal hydroform part. We said all the tooling, it's called special tooling. Any tooling that's specifically tied to a specific part number, so we're not talking about your drills, I don't need drawings of your drills, I need drawings on any tool that is specifically tied to this product to make parts for this product. And so, for us, for the stuff that we make in house, no problem. We're already using UG, it's already in the PDM, it's already released, vaulted, we can deliver it to the customer, we use synchronization, global Teamcenter. Boom. Synchronized, sent to your customer. But we don't do all the tooling. A lot of our suppliers do it, so now on this contract, the suppliers, they have to have their tooling at a minimum, in STEP format delivered to us. They have to actually upload their files into our database, into our PDM, so they have to create the Items, they have to fill out the forms, they have to then start a workflow, so that we then process it and make sure everything's right to accept it, and then we vault it. And that's kind of funny because, it just started, and sure enough, we tested this thing out, it works great, no problem. Well, we tested it on our local area network. The suppliers are coming in through a reverse proxy server. For some reason, don't know why, you use the utility to download, no problem. You use the utility to upload, can't find the proxy server. We're just going, "You gotta be kidding me!" We had this process all ironed out, everything's good, and you find out it's very difficult to test the proxy server when you're inside the firewall.

I'd imagine, even we've run into it, when we want to teach distance classes where for whatever reason, no one can get in, you guys can't get out, from your firewall to ping our Citrix server.

We had this case, we had to get into the customer's Teamcenter engineering database. We wanted to get into the rich client. We put their VPN on our computer, so now we have go from our local client, through our firewall, through their firewall, to the database server. We can't do it. Our firewall won't let us out with a VPN. And there was no way, and our security said, "no way. We won't

open a hole for you.” So then what we had to do was, we have what we call a visitor net. A wireless hosting system on all of our buildings for visitors, that it lets you just access the internet. It’s like your accessing a hotspot. Well we also have it hardline, so we actually had to get a hardline for one of the computers switched over to the visitor network, so that we could go into the customer’s database. You’re just going, “You gotta be kidding me!” I talked to other companies and they don’t have any of problems, why does XXXXX have all these problems? Well, we have a lot of really important stuff that we don’t want people to get to. It’s not like you’d get fired, no, some of our stuff, if people get access to it, you go to jail. We’re not talking proprietary, we’re talking export control, we’re talking secure clearances. I try to explain to people, they’ll be like, “How good is XXXXX with the internet?” It all started with DARPA net, and DARPA net was the universities, the DOD, and the defense contractors. And that was the internet. When people were saying “Hey, we got T100 lines, what do you guys have at XXXXX?” I’m going, “Well, it’s our own thing.” “Well what do you mean your own thing?” “We haven’t adopted the commercial standard, we had our own standard. We were the internet, the military had their own systems, it’s not a commercial system. It’s the equivalent of T-150.” “That doesn’t exist!” “Well it does for us, and we’ve had it for a long time.” That’s always been interesting for people to understand, the troubles that we have sometimes other companies don’t even come close to encountering.

A lot of my research for this thesis has been in what these small manufacturers have to deal with. A lot of them, their customer is a big company like XXXXX, or whoever, so they have interesting and different paradigm than your traditional, even a medium sized larger, not even as big as XXXXX. The customer is the end consumer, for many of these smaller companies, that’s not how it is. So they have to give over their data to you guys, and they get data from you, all the intricacies that go on with that. It’s been fascinating, I read a lot of case studies, they do a lot of case studies overseas, in Europe and Asia, and South America, they really care about their small businesses and the government steps in to help them succeed more even so than here. The crazy data issues that go on how they’re interfacing with their customers, they have one system, the customer mandates that they have to put it in with this certain format, but they can’t afford to put it into that format so lose the contract. Part of my research for this thesis is to find out if American companies have to deal with that too, and if so, to what extent. Your observations about, like the security, the networking type stuff, that’s something they deal with too but they don’t have big IT staff to take care of it, and to protect all that data. There are some very unique properties they have that a lot of these other business, I do research with other big companies, you guys all have great IT staff, obviously XXXXXs got a lot of history with IT security. You don’t want to get hacked, it’s very important, you’re doing government contracting. These small companies don’t have those resources, they

don't have the needs. They're a different breed of business, and to know more about their processes and challenges has been fascinating so far.

I'll give you a good example, you'll like this one. We have Teamcenter Global engineering, the synchronization between databases. The way the OEM made easy as possible, is they have what's know as an ODS, I have no idea what it stands for. Object dynamic server? I don't know. Basically it's a service, usually you put it on another server, and think of it as the master key registry. I can set up a database here, there, they could have the same keys on parts. Key 1 one is a washer over in that database but key 1 is a jet engine in that database. Think of the ODS as the master registry, so if you want to make something available to the other databases, you say "this part number, this item ID is now available to other databases" and that ODS makes sure that you're unique. Versus what the other database says is available, so now you, since you published first, you get that number, as far as its concerned. Then, when you want to send information back and forth, you actually, it was set up as a pull system, so you would say, "Hey what's available on the ODS server? I need this part number, is it available for me to download? Oh, yes it is! Then download it!" And the ODS server says, "Oh, that was published by this database, I know where that database is, I'll go get it," and it grabs the information, sends it to your database. Then your database now goes, "Here's how I get it," and then your database goes and talks to the other database and says, "Hey I wanna import this stuff" and the other database says, "You're approved, you've got the right key and encryption and everything, okay I'm going to send it over to you." It's imported into your database, and you can use it. You've got all the information in your database from the other database, and your database knows that it's a copy, where the master is, and if that master changes, since it knows it's published, the other database talks to the ODS server, the ODS server talks to your database, says this has been changed, your database then goes and gets the last update. Nice system, really works well. We used it were working between Location A and Location B, seamless, really once you get it up and running, beautiful. So then we said well, oh, we've got the customer. We want to synchronize with the customer too. The customer's behind his firewall, we're behind our firewall, ODS server doesn't work! And then we get into it, and we say, "Oh, can we open up these ports and they open up these ports?" IT says "No, that violates our IT protocol. You can do it this way instead, you have to basically send packets. You can open it for a little bit." These ODS servers kind of require a dedicated socket, a port. We had to come up with a whole new system that we had to hand write ourselves, that we don't use the ODS server, we just use the basic import/export capability, but we had to write our own queries, our own exports, we had to have our own SVLP transfer process, it's one of these new secure protocols. That goes through our firewall, and it's a server that's on the firewall, it's part of the firewall capability, then the customer we had to give him a program that automatically queries that server to see if there's a new package there, we had to set up the customer with his own software so that it's put on a cron job, and it

runs at 3AM. Just to get automatic transfer of information between the customer and us, there was no out of the box capability because security said no. SO then later we were looking at, we have an engineering firm that helps us out a lot, and they're on site. We were saying wouldn't it be neat if we could get them to work off site, so we looked at all the different technology scenarios, how can they do some work for us, some subdesign work, or design packages for us. And we looked at it and looked at it, and the IT stopped it. It is not cost effective at all, based on the fact that they can't get our database over a wide area network efficiently. Huge lag time, slowed down load times, it's not our side of the internet, our network guy once explained it to me. If you could imagine the internet, and if you can imagine the internet going to your house is the size of a stirrer straw, like for cocktails? That's the diameter of what's serving your house. XXXXX's backbone for the internet would be the size of a sewer conduit. Whenever we have network problems, once you're to the backbone, it isn't that! You're talking about some other problems, and the more we look at it, you find out that the restrictions outside of our network are such that it pretty much, you cannot do this work over the internet. You've got to be on a high speed local area network, or a dedicated wide area network. So we're like 'well okay, we'll do a synchronized database' and then when you find out what it costs to stand up a separate database, and support it with all these custom tools, you better have a lot of people because that's a lot of cost you have to spread over, so an entire business concept fell down, and it was with a small company, which is what you're looking at. That small company cannot set up a separate business with us due to the security technological limitations. So they have to stay, they have to basically work in our buildings still. They have to work on site, good example. How even with all of our resources, we don't have a solution for a small company. Everyone tries to think they do, but when you look at the penalty of working over the internet, it's not viable.

It's something we can't really do anything about, unfortunately. I read these case studies of these companies, not only are they having issues with the way that they're doing business with their customers, if they have any suppliers, transferring data back and forth. There are a lot of organizational issues that come to the surface more visibly because there's fewer people and the people who are in charge at the top of the food chain have more control over the everyday workings of the business. It's something that really hasn't been studied in the US, in terms of manufacturers and product data management, that's why I'm doing this thesis work. It's fascinating to hear your stories because that's something I would imagine could happen to any company, any smaller company, working with a larger company, whether it's people who are just doing some engineering for you, or it's someone that's doing manufacturing of just a few parts for you, I would imagine it could happen to anywhere.

Some other examples of small companies. Being a government contractor we're required to do business with small companies. We have a huge threshold on this project, I think it was 18%, 18% of the contract has to be small disadvantaged minority businesses. Which is a big threshold, without a doubt. There wasn't enough content just for the detail, simple detail parts. We had to actually get bigger than that, so we're sending subassemblies, good size sub assemblies to small companies. We're sending a huge sub assembly to a major company. It's an international company, over in Korea. For competitive cost reasons. We have probably more of a supply base problems on our program than any other defense program within XXXXX. A competitor probably might have a bigger challenge than us, on their big product. But because we're dealing with small companies, like for a specific product, we have parts done by XXXXX. Well it's a big company, it's not as hard, it's a lot easier to deal with a big company and large amounts of data and complex data than it is a small company. So we've got this challenge. When you get to configuration control in military, it's all done by unit number, so there's effectivity, and basically you can change the configuration by specifying a number, but you don't have the different part number. It's the same part number, but there's different parts in it. The parts change between shipment 1 and shipment 2, so it's a very dynamic, very complex way of configuration control. Basically, small companies, they can't handle it. It's foreign to them, it's very difficult to manage because at the end of the day, you pretty much have to have this stuff in a database. They tend not to be able to have that database, or want to do it, it's very dynamic, and even if they did have the database, they don't have it integrated to their factory floor like we do, because we've done this for decades. Even then they have that problem. So we've actually changed some of our configuration control in engineering to match what our suppliers are capable of. We have this term, "base bill" which mean it's not controlled by effectivity. It's only controlled by part number. You want a different part in that assembly, you have to have a different part number for that assembly. That's how we deal with our small companies. We changed upstream, engineering, to help with the downstream. Now, if a buyer's making a single part number assembly, there's only one configuration for that part number. There's only one thing he has to download. What we also had to do, was because within the PDM, the assembly pointers for the CAD are for Teamcenter Engineering pointers. They're in TC Engineering language. Well, if you just did a raw export of that, into an operating system, the pointer still points to Teamcenter, but you're not in Teamcenter. You're not gonna be able to open up the product structure. We actually take the entire assembly and we export it to the operating system and we get all the pointers fixed, in the OS. There's out of the box functionality now - when we were originally doing this, there wasn't good out of the box functionality - we had to write our own program to do this. Then we take and zip it all up, and we put it back into Teamcenter under that assembly so now the supplier can download all that. But, when we did that, that was at a moment in time. Even though we can't change the configuration, we can change some revisioning. And it's all based on your business rules so I could say I have a part and the tolerance used to be plus

or minus 10, now we're gonna make it plus or minus 20, with the new revision. Since it's a larger tolerance, previous revisions comply. It's a looser tolerance now, so the previous parts comply, current revisions comply, no big deal, so we don't have to roll dash numbers up the assembly. We just treat it as a different revision. But, the supplier still has the the assembly, the models from the old revision. Because I exported it at that time and brought it back in. So we have those kind of problems, too. Here we do these things to help the supplier but now we have other problems with the supplier. Now he's going, "Wait a minute, you told me the latest revision 02, but the assembly that you gave me has a 01 in it, what's going on here?" So if we were hooked up with the PDM we'd have more visibility, they'd open up the assembly and it would automatically configure based on the revision rule to the latest 02 revision. But they're not, and it doesn't, and we have to give them time stamp configurations. Good example of the problems that we don't experience but the supplier does, and the things that we've done to help mitigate it, which then cause other problems.

You're really in it.

I am on the bleeding edge, I am on the front line. I'm taking the shots day in, day out. Everything I mentioned, of this conversation, I guarantee you in the past 4 weeks I've probably had a problem with any one of these things that I've had to solve. It's not like it's all working smoothly and perfectly. It's constant, oh there's a problem here we have to fix it, there's a problem here, oh there's a gap here, we have to fix it. This is the bleeding edge. This is, as far as I can tell, as advanced and capable as anything out there. And this is what we're experiencing today. I was telling the professors at Georgia Tech, I hope you guys realize that what's going on in industry today, you see the product, you see the detail that we've got. It's amazing, that's more than any academia would every possibly imagine, but the funny thing is is that our processes and tools and procedures are not even close to what academia would imagine. There are still a lot of problems, a lot of tribulations, gaps, IT problems, that you're just going like "how can that be?" And it goes back to the original thing, unless your actual product is going out the door, you don't get the same amount of attention. That was the lesson my dad gave me a long time ago, really stuck to me. You'll measure, you'll pay attention to what you're getting paid for.

Interview 2

What kind of pressures do customers at your company exert on your organization in terms in how you're doing design in terms of software and systems?

Our customer base doesn't put any pressures on us whatsoever. If you're talking about our ultimate end customer, the purchaser, they don't get involved. Every time we build an airplane, it's totally managed internally.

How about your suppliers, do they happen to exert any pressure, on how you guys tend to do your design process?

The relationship is in the reverse. We as the OEM, mandate to our suppliers, which applications to use and we manage what revision levels, service packs, and patch levels of the applications that we mandate that they use.

That's just as important. So you tell them which patches they must use, and basically if your suppliers refuse to, you go find someone else, is that how it usually works?

Well, in the design data supplier use case, those elements are included in the contract with the design data supplier for engineering services up front. The applications, the procedures, and the refresh cycles are priced into the contract, those are contract deliverables. On the hardware supplier, i.e., we send data out and they send back aircraft hardware, we encourage the supply base to participate in our electronic data enterprise and give them a requirements specification for assets they need to acquire in order to do such. Those assets include CAD tools, and the requirements to keep their CAD tools in sync with our CAD tool for any given program. Now not all suppliers feel they have the financial wherewithal or the technology wherewithal to enter into that space, and some do. The ones that do acquire the capability, add that capability to their supplier capability sheet that they submit to companies when they try to become a supplier to a new organization, just like you would have capability for milling or drilling or machining or painting or finishing, one of their capabilities is a given CAD capability. Then included in the decision process used to select suppliers, of course in addition to a number of other parameters that goes into supplier selections.

What do you feel has been the biggest hurdle to successfully use PDM within the design process?

Organizational change. The worst organization is engineering, by far. Managing organizational change has been the largest struggle, you can do anything with technology, you can do anything you want with software given the right architecture and support folks. The biggest hurdle by far has been getting the organizations accustomed to using a product data manager and then using it effectively.

Have you felt like there's much push back from the engineers or anyone else in the company, like vocal pushback that they don't want to use this and why?

Tremendous, engineers are very - and I include manufacturing engineering in that term engineering - not just design engineering. Engineers are very creative, free wheeling, energetic, enthusiastic individuals that don't necessarily like constraints. Putting structure to the data that they're generated through the use a PDM tool represents a constraint, although financially powerful, is not initially well received by the engineering staff.

Have you come across any issues with people forcefully trying to not use the system the way it was intended, or tried to sabotage it in any way?

There's always the resistance to follow well-defined procedures, there's also a tremendous resistance to changing behaviors. I wouldn't necessarily say that folks have any ill intent on sabotaging things, but certainly try to perform legacy business processes inside a now implemented PDM tool. It may be a bit of a non designed business process, and they find it so cumbersome that eventually the smoothest way to interact with the system is to mold your behavior to adopt the business case uses that were designed. It's a mind shift.

What would you say has been the best effect of using the PDM system in the design process given the difficulties you guys have had with organizational change?

Drastic improvements with productivity. Access to data.

Even though there's still a lot of resistance to using the tool?

The resistance eventually fades and crumbles. Or, individuals get retrained and/or get refocused. The emphasis is placed upon them that their job duties include these specific functions. And in order to maintain their job functions they need to go these processes. So it eventually does work itself out, it's necessarily always on schedule, from the engineering. But to have an attribute-rich configured database of the engineering that's accurate, and complete, at the onset of a program, is financially invaluable. The leveraging of that information through the rest of the organization creates tremendous benefits in the form of improvements in productivity. I call it the productivity bull-whip. That leads to lower costs, shorter cycle times and higher returns. Market margins.

Given all that good stuff, what do you think has been the worst effect of having the PDM system implemented and how it's affected the design process?

Second to organizational change would be, impact to IT and IT infrastructure. PLM and PDM tools, at least in our organization, are not implemented and managed by the IT folks and the collaboration and coordination with the applications deployment team and the network support folks from the IT organizations, is challenging. These PDM tools are very chatty. You can drag tremendous volumes of information across the network that you didn't have that capability before. It puts significant demands on the infrastructure, and as the programs grow and as the headcount and the license install base or named users grow, the load grows exponentially on the network. And it's competing with today's mobile computing folks and competing with the iTouch and iPhone folks who draw tremendous amounts of bandwidth, so when you couple PDM and PLM on top of it, it creates quite a challenge for the infrastructure folks to keep up with.

If your IT people aren't managing the PDM system, who is?

We have a separate organization that bridges IT and the business areas. Our separate organization is actually positioned in the program office. We manage all programs, from a data perspective.

I would imagine that's got some good advantages, because of I know these PDM/PLM systems are in theory getting to the point where they're going to start touching lots of different parts of the business besides just engineering so I would imagine having you guys sit in the program office and be in the central area where you can see how all the projects are going and make sure that the PDM stuff gets properly implemented in all of that would be very useful.

That is key to success. Is knowing what the program requirements demands on the PLM and the infrastructure are going to be before the programs get launched, and are included in the budgeting, and the productivity gains and the ROIs of any given program.

In my experience I've found that a lot of these companies that start implementing PDM systems, they don't sound like they have as much forethought on how much it's going to really affect every part of the business, so instead of having the PDM system being managed out of the program office, it's its own separate project and its own separate place and so it's not really connected to the rest of the IT project management stuff so it's really interesting the way you have it set up because I haven't really heard anyone say "Oh yeah, this is our initiative and we're going to manage it this way."

It's akin to in the operations world, ERP. And sometimes when you drive ERP systems out of the IT organizations typically fails as well.

What do you think has been the biggest effect of the PDM system on your daily job duties or the job duties of people you've been working with?

It's created an entire new career path. A whole new career structure. It's a whole new discipline to itself, and it's an organizational structure with a career path that's not engineering, it's not operations, and it's not finance. It's all to itself, called "PLM."

That's very forward thinking, I don't think a lot of even big companies have gotten there yet.

If you do a correlation between their organizational capability and how PLM is managed within their organization success rate, I bet you'd find those to be negatively correlated.

I would not be surprised!

It would be an interesting correlation.

(Laughs) Yeah, that's like another master's thesis.

Let me go back and I'll tell you a quick joke on the daily job duties. Because this PLM stuff touches everybody's job, in some fashion throughout the whole organization, the folks that do the implementation become the face of the project, for all the good and/or bad. So the perception from the users can be very bad but the perception from the management can be very good, vice versa, perception from the users can be good and the perceptions of the managers can be bad. In theory it all works out and everybody has a net benefit. So when you get into this business, there's a scenario called the hero or the goat. And in this business, you're either a hero, or a goat. And nobody wants to be a goat, so you start out being a hero, but you can't be a hero forever. Sooner or later the system's gonna crash, the user's gonna have problems, the software's not gonna work, you're late on delivery, whatever. But sooner or later, you become the goat. And if you can make it from hero to goat and back to hero again, you've got some legs in this business. Not everybody makes that cycle.

I would imagine you've been in that position where you've gone from hero to goat to back to hero again.

I've been through that cycle so many times I have bipolar disease.

(Laughs) So is it usually management versus users, or are there other people involved?

It can go either direction, I've been dressed down in the morning from senior management, and literally by that afternoon, by that evening been at an awards banquet getting accolades for something completely different by the same senior management. I've been praised in the morning by the users for accomplishing some deliverable on time, some capability, some functionality, some productivity gain, some performance improvement, and then by the afternoon, another set of users, you're the goat again.

Interesting, thank you for your candid comments. I'm just starting breaking into it myself with what experience I have.

Managing expectations is very difficult. Setting expectations and managing scope is very difficult.

So given that you've obviously been in the thick of it for a while and have seen the positives and negatives, what is your impression of PDM systems in general, like where the software is today and where it's going in the future?

Well let's just talk application first. There are different levels of capability in PDM systems, there's base file management, there's baseline data or attribute level management, you can go up the chain of capability, you'll get into configuration management, instance management, space management, and then enterprise level distribution. So there's a chain, and not all applications do them all. Some are positioned on the low end, some are positioned on the high end, they try not to overlap them, not all companies are good at the space either. Some companies have strengths in one side and other companies have strengths in another side, the technologies are also diverging. Some companies are very good at and are focused on sophisticated file management, and other companies are diverging from file management into pure database management. There's quite a span of capability and technology and technology thresholds, and it depends on your industry, your lifecycle requirements, and your capital spend appetite, as to what level of capability and what application is the select for what capability you would need on a particular project. What's my impression? The good ones are good, the bad ones really suck. I could give you a laundry list of what to do and what not to with what applications from what supplier but I don't want to throw supply into this conversation. I'll tell you, all salespeople oversell their product by 20% regardless.

Would you say that, especially when you guys are trying to interface data with your suppliers, how has that been working out for you? You guys obviously use a more database oriented scheme for managing your data instead of just thinking of it as files, but when you're talking to other companies that you're trying to share data with, and they have a different

outlook on what the PDM system is supposed to do and how it's supposed to work, how have you guys been able to work out those differences?

Well, there's two different use cases there. Again there's design data suppliers who are contracted to perform design services as a deliverable. That's a different data world than build to drawing or build to model suppliers who have a one way data dump from OEM to supply base and send back hardware. On the design as a service, design data suppliers, we have those suppliers highly integrated into our system, where they use our same applications, and our identical PDM and CAD tools, outside our firewall, and they're connected through secure high speed VPN, secure DMZ type operations through the firewall. So if you look at business processes, our category 1, our highly integrated design data supplier behave as if we were just extending our design room out beyond our firewall. So those suppliers, even though those employees or those users are not employed by our company, they're working on our project and they behave exactly as if they were sitting inside our firewall being employed our company. As you go down the data supplier food chain, shall I say, where the data supplier is not supplying design data for our particular company, and they're providing design data for integration, design data of their own, to integrate into our product, i.e. components, vendor supplied components where that supplier owns that design, we also bring in data from that level of supplier integration, but it's basically through an FTP site with a transmittal and an acceptance, it's not real time, design integration into the design realm. And those folks don't necessarily have to use our software, because they're just managing essentially files through an FTP site. They can use another design software, provided both the supplier's design software and our OEM design software both have some type of standards based interoperable layer they communicate through, with validation. Now, the build to model, or build to drawing suppliers, we manage the CAD space for them as far as viewing our data, but we do not integrate through a PDM tool, the build to model or drawing suppliers. That becomes very complicated from a security perspective.

I've heard stories of cases, similar to what you're talking about with you contracting out services to them and them delivering a design, they're trying to do the same thing but literally they wanted to move that company off site, outside of their firewall environment and they just could not do it because of the security issues, and that's just data. They do cost analysis on it and it was going to take vastly more money just to let them go work at their own office rather than have them actually have sitting on site at the OEM.

We spent several hundreds of thousands of dollars getting this one supplier stood up.

And it's one thing for larger OEMs to have to deal with that, but for smaller manufacturers, whether they're delivering a service, design wise or

whether they are delivering the final product that can sit on your desk, they still have a lot of issues talking back and forth with their customers, you guys, and figuring out the best way to get that data across in a secure manner that satisfies both parties.

It's a difficult problem.

So this last question is a bit weird, everyone I've been talking to is involved in the PDM/PLM system itself so they probably all have a bit of bias, do you feel like PDM systems have positively or negatively affected the company, your organization, the industry as a whole? Do you feel like it's kind of like a wash, or what is your read on that situation?

Well, PDMs are applications that are just technology enablers. The use of a PDM tool and the strategic deliverables of a project that includes the use of a PDM tool need to have far more reaching objectives than just implementing a PDM tool to return value. Because of the PDM system is nothing more than a technology enabler. At XXXXX, it's provided tremendous value and phenomenal breakthroughs in productivity levels, unprecedented for the company. We measure everything in hard dollars and budgets. Everything comes down to operational expense.

That's interesting. I've heard from other people I've talked to that trying to monetize the PDM system in the way that they would like to has been very difficult for them, it often comes down to the amount of time it takes someone to do a task, before and after implementation, that's really the only gauge they've been going off of. So beyond that they've had a harder time trying to sell the improvements to upper management who, all they see time that is saved, but if that's the only thing and there's a lot of investment up front with software licensing and all the work that goes into implementing it, it's been a hard sell for them.

That's why it's got to be budgeted up front at the beginning of the project as part of a implementation project and not bolted on afterwards. We track everything in hard dollars. At the end of the day everything has its marginal contributions to earnings, and improvements in margins is tracked. That's the leading indicator.

There are other indicators too, but I would agree that money is the easiest one to measure.

At the end of the day, we're an organization that represents the interests of the investors, so we have fiduciary responsibilities to improve margins, to provide value to our investors or they'll go elsewhere. So that's what PLM and PDM tools do when properly managed, implemented, and coupled with, as technology enablers, to implement other business objectives. To just spin up a CD with an

application on it is not going to gain any dollars, it's gonna cost money. You have to use it as technology enabler in order to accomplish other business objectives, reduce cycle time, lower cost, improve margins.

Interview 3

What kind of pressures have customers exerted on your organization in regards to what design software they're force to use or asked to use?

We don't have customers like that, but working with the manufacturing community, suppliers are sometimes pressured to use the same software as their customers are using. That makes exchanging information easier as far as the customer's concerned, but puts a lot of cost on the supplier. Software can cost a lot of money, if you have multiple customers you might be required to have multiple software systems to accommodate the exchange with the customer, so that can be a real problem.

Would you say, in the examples that you've seen, do you feel like those suppliers had a difficult time changing for their customers, or did they kind of roll with the punches?

It can be really difficult, it depends on the relationship with their customer, if their customer is their only relationship, if they're totally 100% complying with someone, some specific company, let's say GM or something like that, then they are more likely to change their systems over to accommodate that customer. That can be a real problem, it really can cause them to not be flexible enough in the marketplace, and somebody like GM has financial difficulties, a lot of people went out business because they couldn't react fast enough to get other business. They were tied into one specific customer too closely. So that can be a problem. It's been onerous to comply with multiple sets of software requirements from different customers. A lot of these companies don't want to do it, they want to just keep their own systems and be able to bring data into their systems from their customer's systems without having to change their systems over to match their customer's system. And everyone's got the software environment that they like to operate in and it can take different flavors. Even if you've got the same software environment as your customer, it has to be exactly the same. So say I'm a CATIA house and if I've got just a slightly different version of CATIA that can cause problems. I could be out of phase with the versioning, I could be one whole version out, that's a big issue. And also, something, like a PLM system, that's just exceedingly expensive and makes no sense for a smaller company. They could use a smaller, less capable PLM/PDM system that works for them, or even just a database or something that they set up themselves. That's gonna be completely sufficient, but if their customer wants them to have the same exact PLM system, they could be looking at huge costs per seat of that system. The licensing sometimes doesn't make sense for a small company, whereas the licensing

might make more sense for a really big company. Using that same licensing model just doesn't work.

What do you feel has been the biggest hurdle to successfully use those systems within the design process?

The biggest hurdle so far is a cultural hurdle. It's to get the whole organization to adopt the philosophy and the rigor that you have to have to use those systems. So for example, if you've got a company and you have, engineering and analysis systems, often you'll find that they store their files somewhere, they might even back them up but there's no real rigor and discipline behind doing that and if you adopt a PLM/PDM system, now you're having to check files out, and have the information to do that, set up all the permissions, if I check a file out, I check it back in, that's a lot more disciplined than people might be used to, but you have adopted that philosophy, that everything I do impacts someone else, and I can't just make changes to this design on my laptop at home, and not expect that that could impact somebody down the road, by my not doing it in a very disciplined way. Because now that you're in a PDM system, if I check something out and make changes to it, there's a notification that goes out that says there's been changes made to this design, and that alerts everything to say if I'm doing some complicated analysis on this component, and I know the design people just changed it, maybe I'll stop doing it till I find out what they've changed, it might totally negate several weeks of analysis that we might do. When I was at XXXXX we used to run into that all the time. We would get manufacturing lines set up and then we'd get hit with a design change and we would find out that that design change had been in the works for the last couple month, and if we had known exactly what it was, we would have changed or stopped till they came out with the new revision to the design. So that discipline pays off tremendous dividends and makes sure the work isn't done against the wrong versions of things and there's no reentry of data, you're entering data in once and using it multiple times, but it takes a lot of discipline, and it takes understanding that now you're in an environment where you have to have permission to do things, and it might be you're gonna lose some convenience in not having things on your local hard drive and not operating like an independent entity anymore, that you have to log into the system, you have to check things out, you have to check them back in, you might not have access to things, because everything's access controlled now. So that's the biggest barrier. Maybe 10 years ago there were a lot of technical barriers, because the database systems were a little bit flaky, but those systems seem to be pretty robust now.

What do you feel has been the best effect of using PDM systems in industry design processes?

We just visited a company that implemented model based environment that incorporates PDM/PLM systems. It's just a tremendous payback in efficiency,

because I'm reusing data, I'm able to know that I'm working on the correct version of something, I'm not wasting time working on something that someone is planning on changing. A design that's up for review and we've tagged it that this particular component is going to change, somehow, we're not done with the change yet but it's on the list for being changed. We've at least made that determination, so I can go off and come back to it later. Just the reduction of errors – reentry of data causes a lot of errors. If we're able to use the data from one system to the next, if I can take it from the design system to the analysis system into the manufacturing system, I give it to my suppliers, I can validate if I do translate something, I can do a validation on that and certify that that's good translation. All this stuff just really starts paying off. But if you don't follow the rigorousness of it and change the culture in your company then it doesn't pay off as well. But we're seeing return on investments that people think are a joke, because they're too high! They just don't believe it, you can't have that kind of return on investment, that's a silly number. We're seeing reductions in time, you're looking at going from months to hours, weeks to hours, that kind of reduction is not 4 weeks to 2 weeks, it's 4 weeks to 1 day. Or something that took me a week now takes me an hour. It's just big huge unbelievable reductions in being able to process stuff, so it's really amazing.

So what do you feel has been the worst effect of these PDM/PLM system on the industry's design process?

I don't know about a worst effect... they're really expensive to implement, it's tough, and they don't scale really well, so something that works for a small system doesn't scale really well, and for big gigantic systems, they're very difficult to implement over a very large enterprise, and to coordinate the implementation process across an enterprise like, the Army. It's very difficult for them because they have multiple organizations within their organization that don't want to use the same exact environment. Which should be okay, in theory, but it's just a tremendous amount of work to get all the systems integrated. So if you're gonna work in an integrated environment, you've got to integrate all your systems and on a large, large scale, that's extremely difficult to do. A lot of problems with people trying to implement across gigantic scale.

What do you feel has been the biggest effect of PLM/PDM systems on the daily job duties of your average engineer in a company or your average designer?

It's totally changed things for the individual engineers because it almost makes everyone like a super engineer. You really can do a lot more, and you really do spend a lot less time worrying about getting data from one system to the next, reentering data; it has several effects. It gives you the opportunity to do more, but it does limit your opportunities to use the system that you like to use, because if you want to use system XYZ to do design and analysis, and that particular piece

of software doesn't fit within your system, your company's systems, unless there's a real good reason, you're probably not going to use it. You're gonna stay within the family of software that that software vendor offers. If there's a really compelling reason to get that system to be able to translate within your environment, and sometimes there is, then you'll do it, but some of the translations are not optimal and that can be a problem, but I think generally once people get over the cultural shift that you need to get over and get used to a disciplined environment, a controlled environment, they're much happier and things work much better. They get a lot more done, things take a lot less time.

In that same vein, have the people you've been talking to doing very much integration of differing systems that weren't all offered by the same vendor, or are more and more companies going towards the single vendor, single solution, completely integrated out of the box kind of systems?

People will stay in the single vendor solution to a certain extent, but like I said, once they identify a particular piece of software that they want to use, they'll use them, and then they'll suffer whatever it takes to get that integrated into their system. It kind of depends on where you are. If you're in the design and analysis, simulation level in the enterprise, it's a lot easier to stay within the family of systems, unless there's a real niche. Then you start getting into the PLM environment, you probably use any one of a couple PLM systems that will work. You don't necessarily have to have the CAD system that goes along with that PLM system. Then you get into enterprise, ERP kind of systems and those are just big Oracle databases, with some front end. Then you're writing some sort of integration or custom software, or you get an integrator. I think for the most part people tend to stay inside their software environment, but you've got to understand. If I'm a small company with SolidWorks, SolidWorks doesn't offer all sorts of analysis packages and all sorts of simulation packages that go with SolidWorks. You'll have to go get something and use it. Whereas if you're in, Dassault Systemes environment and you're using CATIA, and DELMIA, you've got a lot of powerful analysis and simulation tools that are within that family. You might have a hard time a system that's outside that family that really made a lot of difference from the one that was inside the offering. It kind of depends on where you're at.

What's your overall impression of PLM/PDM systems and where they're going right now, whether they've really been a positive force or a negative force in the industry, how do you feel about them today, and I'm personally curious, where do you feel like they're going?

First of all I feel like they've been a tremendously positive force, I think they're getting better and people are using them, and more and more company are moving in that direction. I think where they need to go are lower cost versions of

their systems so that lower tier companies can adopt their systems, and then have links into anyone that's using the more expensive version of that system. Companies are adding capability. Let's pick on ProEngineer's Windchill system, they're looking providing one button push kind of thing to produce a technical data package for the Navy. If, for example Pro/E understands what the Navy's requirements are, they can say, "Run this command inside Windchill, and it'll produce a technical data package for the Navy." So if everyone's in on those types of agreements on what the requirements are, what the Navy wants, and the software providers can understand that, then that's a tremendous advantage. Also complying with environmental regulations. Theoretically, all the data is inside your PLM system, it's in the CAD files, it's in the metadata in the PLM systems, and now I have to produce some sort of document to sell my product in Europe, because there are regulations in Europe that say you have to report all the chemicals you used in your product. That could be me running a process overnight on my PLM system that my software provider is providing me to generate this report to send to the European authorities. Or, I can have my engineer sitting around for 3 months putting that together. One's gonna cost me virtually nothing and the other one's gonna cost me millions of dollars. In terms of being able to get at your data, organize your data, provide different views on your data, comply with regulations, you're just gonna have to have these kind of systems going forward, I don't see how you can get away with not having them. Some type of something like that. It is commensurate with the size of your company.

Interview 4

What kind of pressures do your customers tend to exert on what kind of design software your organization is using?

None at all, actually. We have a couple of people in mining that, they request things in their software, but with software doing what it's doing today and what we've found works the best, is we send them a generic form which is a STEP file, and/or IGES but STEP is a lot nicer because STEP is actually solids stuff where IGES is lines points and vectors. But other than that, we don't generally give them the opportunity to tell us what kind of software to use.

Do you have many suppliers, then?

Tons of suppliers, purchasing's trying to narrow them down, the same sort of thing. They don't push that issue. Some of our larger customers, GE, GM, they send things in the format they want to send it in, and we find a way to make it work. The one place there is some pressure and that's only just from what I've heard, I think GM and GE both push orders through an electronic system, as opposed to paper or anything like that. There was another place, order tracking, and our customer service people are often pushed to use a web page with a password to track things back to the customer. Again, they're the ones that push that.

But you guys probably don't give them any of your data?

None other than what's pertinent to them. They're shipping their box numbers, but none of the design data.

Okay, that's what I was getting at. I know sometimes what happens, small companies sometimes have to give over a lot of their designs, along with the product that they gave to their customer, the larger OEM. They have to put it in a specific format with a lot of different peripheral information, so that's been something I've only read about but haven't actually talked to a lot of people who've had to experience that.

Some of our custom designs are that way, and in those instances when the customer gets everything, they have paid for everything. We make them pay for the tooling, we make them pay for the patterns, and they pay for the design. But generally the real cost is in tooling and patterns because if we've gotten that far with them, they're going to make the order here, and then the other costs get kind of rolled in. Such that we show ourselves a profit, so therefore the design time was paid for, but only in the piece price.

So what do you think has been the biggest hurdle, I know you are in the midst of implementing a PDM system. What do you think has been the hardest part for you guys so far?

Trying to get it organized. I'm somewhat under the gun with finance because I took some of their money and we bought PDM enterprise, and in a utopian world, and I think that's why you found a lot of foreign companies are using it more and product lifecycles because they're starting fresh. We're XX years old last summer, we come from basically word of mouth, finally to paper, to some written instructions, to CAD, and as early as XXXX, was our first time with using an electronic scheduling system for the production facility. We installed MRP 2 in XXXX, and prior to that, everything was handled by paper. It is a small company yes, but it's a huge battleship for us because it goes from being nearly bankrupt in the '90s to hundreds of millions in sales last year. But to push what once was at one time worth of mouth "this is how you do it" to full electronic has been really painful. They're not that easy to turn, and with MRP in place handling the buying and productions and shipping schedules, a PDM system or a product lifecycle system doesn't work well with MRP. I don't know much about the product life, but the PDM system we've purchased can reach fingers out into our IBM MRP system, and bring data back, but they're not gonna be real excited about letting that simply be a storage device and the PDM take over their planning, they're just not gonna let that happen real quick. I sold it to the operating committee because primarily, what it's gonna do for me right up front is save my operators about 25% of their time. And all kinds of good side effects are gonna happen by not running

traffic across the network as heavy as graphics does, it's gonna free up the network more than people realize, but I don't know how to put a number on that. But I could show very very low end, that I can save operators about 20% of their time, and that will pay for the thing in about 14-15 months. The biggest hurdle would just be getting everything organized, our design group is chaotic, helter-skelter, last/lightest/loudest, and there haven't been organizational rules put in place because the people ahead of us have been so afraid that organizational rules would squelch creativity, which isn't the case. They actually make things a little easier to do. I have a person that's doing that for me, she fortunately is extremely organized, and knows very little about what we have going on so when she runs into all kinds of duplicates and things being in places they shouldn't be, she brings it to my attention and we get it to where we should be.

What do you think has been the best effect so far from what you've been able to see from putting that PDM system in place in terms of how you guys have been designing things?

It probably hasn't done a lot for design yet. It will because a lot of things will be easier to find. Right now if I want to find out if I've used a hardware part some place it's a long and arduous process so I end up with multiples. Under purchasing is buying the same thing, under 2 or 3 different part numbers. Once this is in place it will help that. It'll also help us look at things quicker I think, and be able to do some similar practices from place to place rather than reinventing the wheel each time. It's brought an awareness to people to, that we're doing an awful lot of duplication that we really don't need to be doing.

I know you mentioned earlier that you have disorganization, everything's going everywhere. What do you think has been the worst effect of having to going through this PDM implementation, from whatever aspect, whether it be the design process or purchasing, or ordering or anything?

Well the worst effect has been the person I hired recently to get some of the stuff done I'm supposed to get done is now working on that almost full time, so my load doubles. It has caused some pain for people in opening up the old stuff that's not where it was before and they have to go find it. We're at this point now we're at what we call a test load, we're going to copy things over to the PDM system, and we've asked some people to help us try to break what we created. Once we get it tested and we get our error messages down to very small, we're going to actually really load the data over so it will only be in the PDM system. When that happens, there's gonna be a lot of pain because things won't be able to find each other, we'll have to go back and redirect everything, and each time we open something old it'll have to be redirected one more time, and once it's redirected it'll stay, because once it's in a PDM system then you can move things and it keeps its own records. But that will be painful. We're trying to push it now in that we are a little slow right now because of the economy, and if I'm going to

have slow downs, now would be the time to do it as opposed to oh, 3-4 months, a quarter from now when things pick up.

That's a good point, a lot of companies, now that there's a downturn in the economy, don't want to invest a whole lot more into this infrastructure and trying to fix the processes that the PDM system is supposed to be tracking. But really when you have a lower volume, that's probably the better time and try to break into it and start getting into all the issues that will come up eventually, now, when it's a little bit slower rather than the peak of everything.

For a little while it will. And to get US corporations to invest when things are slow, is contrary to their whole thought pattern since all they're trying to do is conserve cash, and so they're not going to make those kind of investments when now is the time to do that. Because you aren't maybe as busy as you could be, our production side is down quite a bit, our engineering has been quite busy and we haven't really had a lot of time for this, but see the opportunity. As you said, when you're busy fighting fires, you don't have time to figure out whether you're following all the rules to get the fire out, you just want the fire gone.

Would you say that that is something that as a smaller business, you guys have an edge over these larger corporations, that you guys can have the foresight to say "look, this is really when we need to be figuring this stuff out rather than 6 months or a year from now?"

Probably not, I think it's the guy that's in charge right now that has a little more foresight in generally, historically, I've been with this place for XX years, having been something like this before. Generally it's just been don't spend anything that you don't have to. This guy is at least seeing that now's the time to do some of this stuff. Contrary, in a large corporation, things like this can just be done in spite of. \$100,000 isn't that much money, and you could probably slide something like that through and no one would even know about it. Here, we have XXX people, and 100 of those are office people. You don't slide a whole lot by. It gets scrutinized pretty close. In a bigger corporation, you can probably pull something like that off if somebody's of the mind to do so, easier because it's really small.

You're probably fighting different fires now than you were maybe 5 or 10 years ago, what's been the biggest effect of this PDM system on your daily job duties and the job duties of those around you?

It's bringing more organization, since it's going to be a system, part of what the PDM is going to set up is process flows. Processes that have to be done. They're set up with specific process gates that this has to be done before that can be done. It's generally done that way anyway, but it wasn't formalized, so being formalized it takes a lot of guesswork out, and it doesn't take somebody that's

been here a long time to remember what the next step is because the next step will be presented to people. I think that will be the most positive effect, and again that's a hope because I don't have it in place yet, but I can see those things being there, just in constructing those flows, you sit down and look at what you need to do and to generate those electronic flows so that they happen correctly. It gives you an opportunity to look at what you've been doing, what you think you need to do, and try to keep them as simple as possible so it's not overwhelming. So you open up the process and say "ah, they're taking on the world" Keep it simple.

The term I'm typically used to hearing is "workflows" so it goes from one person to the other person, approvals, etc, release, all that stuff. You say it's very chaotic now, and at the same time you're trying to define processes concurrently to the defining them in the PDM system, is that an accurate representation?

Yes, there are workflows, but they're not formal. Therefore not being formal, and not being written down, it's easy to circumvent. If we kept the workflow in present form, and make it formal, then it's tougher to circumvent and it also keeps you from forgetting something that didn't seem important at the moment but comes back and grabs you later.

A lot of companies that are doing huge million dollar enterprise wide PDM implementations have all these terrible issues because they have a system in place already, outside of the PDM system, so they can't get the PDM system to reflect the process that they already have in place. So their huge battle is to figure out whether to force the software reflect the real life process, or change the real life process to reflect the software already does out of the box. That's been one of the biggest complaints is the fact they have to make people change the way that they're doing their job every day which is one thing, but then they have to say it's either that, or try to write custom code, and that's just not gonna work out. It's very interesting that you guys are in the midst of clearly defining your processes and so the PDM is kind of forcing you to do that, more quickly than maybe you would have otherwise.

Absolutely, and that maybe one of the things that a small company doesn't have. There are obviously workflows, you can't make parts before you do the drawings, but often times we try to react so quickly that we try to things simultaneously that just have to be done in serial, then you get in trouble. By making it formal, which is what PDM is going to enforce, it will be a frustration for some people to try to push stuff through at breakneck speed but it will also keep us from making those mistakes that, once it is there and it isn't what the customer wanted, we start over. Where, with some sort of semi locked in formal process control or workflow, we won't miss those things as often.

What PDM system you guys are using now?

PDM Enterprise.

And what company makes that?

InFlow. Inflow is making that and it's a gold partner with SolidWorks which is our CAD software.

So your SolidWorks files pretty much talk natively to the PDM system, no problem there? Yes. So given that you are running that middle tier of PDM system, not enterprise level but not like office of 50 people level, from what you've dealt with so far, what's your overall impression of how it's been working out for you guys as a midsized company?

I think it will work out well. Those that have been on the fringes of it, with some of the things we've told them it has the ability to do, it's going to make things easier for them. This company relies a lot on its engineering group, and the purchasing people, are primarily clerks, they're not very technical. This is going to get technical information at their fingertips because once it's up and running reasonably well for what we want it to do which is control our CAD data, they will then be given access as viewers, and they will be able to view that stuff without having to come over here and get someone from engineering to help them. It's also going to affect our production people because we have plans to bring the CAD system that they need access to live to the assembly benches where now it's all still done through a paper system.

Along with the PDM system, are you guys gonna have to buy a lot more seats of SolidWorks?

No, because the PDM viewers and the other folks that can use the system won't be CAD involved, because the PDM will handle Office files, and they already have Office, so what will need to happen is either someone here will need to teach their group, or we'll just set up work flows for them to handle their type of data, and merge it together.

Given that this PDM is going become really ubiquitous throughout your business, do you feel like it has positively or negatively affected your company as a whole at this point?

In our little world, positively. When it gets to their world, it will positively affect them. What I see in the utopian PDM is a single Windows page on each person's computer and depending on their clearances, there'll be tabs across the top. And they can see what parts are running, how many parts are running, how much

they cost, where they run, how they're created, if we have any on order, and how many we're shipping, all those things will be on tabs and depending on what their level of access was, they could just look at those tabs. Right now to do those things you have to know about 30 different screens and remember them. In the business system you have to know how to operate a print system, you have to operate various groups of peoples' spreadsheets, and there's no one here that knows all those things. The PDM could pull all those things together for them. Whether the personality of the company will let that happen, might be the next hurdle to cross. You can sometimes get territorial over what they have access to.

That's kind of what I was getting at, do you see that being an issue later on when you've got people with all different levels of permissions, and can only get to certain things that before they were able to if they knew so and so in department next door? Do you think that's going to be a problem with people not being able to easily get the data that they could before?

No, I don't think so, since they can still go next door and get the information if they want to. I'm very fortunate, I touch every department in the company, seldom as I am in my office! But there are a lot of people in this company that work in their own little cube and that's where they stay. They really don't know what goes on outside their cubicle. It'll bring them information that they maybe didn't know they could use, I don't really see a turf war problem there, not a very strong one anyway, because I think the benefits will outweigh whatever fear they have of losing control.

That's a bigger issue with these larger corporations than smaller companies. With the level of siloed-ness, the mentality of this is my data and we want to do it our way, and just because you want to do it this other way doesn't mean we're going to do it that way even though, in reality it's the best for everyone if we just all do it the same way, so it sounds like you won't have as many of those problems.

I don't think so because there just aren't as many opportunities to create the silos here because there just aren't enough people to pull that off. I think the larger corporations, a lot like our own government, there are people that have to keep that stuff secret or they wouldn't have a purpose.

Appendix C. Qualitative Codes

Data retrieval

1. Decreased times, productivity increases
 - a. Productivity gains
 - b. PDM leads to increases in productivity
 - c. PDM increases efficiency
 - d. Primary benefit will be time savings
 - e. Duplication of efforts and finding information is time consuming. PDM should remedy this
2. Object-based data
 - a. Breaking data down into database objects
 - b. Breaking data into smaller pieces yields efficiency
 - c. 20 years ago, rare to have system to handle data objects
 - d. Tradeoffs of speed – sometimes if object-oriented isn't available, next best thing is to use brainpower, not modify the system
3. Querying
 - a. Querying = major PDM strength
 - b. Ease of fixing query mistakes
4. File management
 - a. Frustrations with systems based on files, no objects. Time waste
 - b. Differences in retrieval times with object based PDM vs traditional file based systems

Data flow beyond the design

1. Single entry
 - a. PDM = single source, single entry
 - b. Single entry
 - c. Single efficient entry
 - d. Single entry for many downstream uses
 - e. Form relationships simply and early
 - f. Single entry means less time spent
 - g. Less data reentry, fewer errors
2. Integration of PDM
 - a. Integrate CAD is essential for PDM to reach its full potential
 - b. PDM is a data source, but the data can be used in many places
 - c. PDM is becoming more integrated throughout the business
 - d. Integrating people and presenting data efficiently will require people to branch out and see the bigger picture more
 - e. Less need for purchasing to be depending on engineering
3. Downstream work
 - a. Flagging that “this will change” prevents work
 - b. Saves downstream work

- c. What the engineering and upstream people think is important vs. what is crucial downstream
 - d. Downstream problems sent back upstream can be confusing to interpret by engineers
4. MRP
- a. Tracking data connected with tooling along with the design definition
 - b. MRP & PDM integration faces many limitations. Mindset and software limitations
 - c. Bringing CAD to assembly floor

Data exchange with customer, supplier, other sites

1. Data formatting for exchange
 - a. Exchange with customers, suppliers, system integration
 - i. Contract states requirements for data handling
 - ii. Customer driving how data is handled very stringently
 - iii. Customer used to be lax on data handling and transmission
 - iv. Can mandate supplier's software by only sharing data in one format
 - v. Mandate to suppliers
 - vi. If suppliers want to become regular supplier, they must follow OEM guidelines
 - vii. There can be a lot of issues communicating with suppliers
 - viii. Suppliers doing data are completely integrated with OEM
 - ix. When supplier provides design data and components to add to project, less integration
 - x. Component supplier, no integration
 - b. CAD data
 - i. CAD data formatting requirements
 - ii. CAD data formatting requirements
 - iii. Translated neutral file formats are still used with suppliers
 - iv. Generally use neutral file formats to communicate with customers
 - v. Larger customers tend to give data in the format they want, supplier must make due with that
 - vi. Sometimes, give supplier their choice of format to use
 - vii. Suppliers would rather not change
 - viii. Suppliers juggling multiple customer softwares can have difficulties
 - c. PDM data
 - i. No PDM industry standard
 - ii. Data compatibility
 - iii. Do all work then commit it to PDM in correct format at one time
 - iv. Change data formats up front for compatibility later
 - v. If not all going to same system, integration issues arise
 - vi. Audit program to ensure suppliers have some kind of digital system for basic data handling

- vii. When suppliers deliver products, they also deliver tooling information along with it, and must enter it into PDM accordingly
- 2. Data Delivery – Present and Future
 - a. Contract requires data package
 - b. Requirements are in contract
 - c. Data delivery
 - d. Data more up front product, not just byproduct
 - e. Trending towards data as a product deliverable
 - f. Data as product & product deliverable
 - g. Customer isn't paying for process, but product, including data
- 3. Systems compatibility
 - a. No customer involvement
 - b. Large OEMs struggle with small suppliers
 - c. PDM syncing across sites is not so bad if you stay within preset, planned for boundaries
 - d. Problems arise when suppliers aren't on same data revision within their company
 - e. Easier to comply with one big customer, but limited flexibility and possible problems
 - f. If customer requires complete integration, can be costly
- 4. Security issues
 - a. Security issues
 - b. Security is expensive
 - c. Sometimes hard to exchange data with suppliers who want to get offsite
 - d. Communicating data with suppliers through firewalls is so difficult
 - e. Data exchange through security using PDMs is very difficult – no out of box solutions
- 5. Process change to accommodate data exchange
 - a. Trying to help suppliers also can create PDM problems
 - b. Example of changing processes so small companies can cope with product configurations
 - c. Process changed to help suppliers
 - d. Not software, but processes are important
- 6. Data Delivery – Past
 - a. Lack of PDM data delivery requirement
 - b. Contract data handling not common
 - c. No contract data handling before

General PDM characteristics

- 1. Out of the box functionality (big vs. small)
 - a. Generic PDM out of box
 - b. OEM PDM... lowest common denominator
 - c. OEM PDM has gaps

- d. Generic system isn't well matched to existing practices
 - e. OEM PDM vendor takes too long for some solutions
 - f. OEM PDM can't plan for all use cases, manufacturer must get creative
 - g. Database systems not the hurdle they used to be
 - h. PDM must be chosen based on company needs. Not all PDM is good for everyone, must play to strengths
 - i. Smaller PDM/PLM is better for smaller company
 - j. Needs more versions for smaller companies
 - k. Software vendors are adding more automated functionality
 - l. PDM is expensive and complex
 - m. Despite all the resources, even the best PLM/PDM system has a lot of problems
2. Workflows
 - a. Digital signoff and workflows are advantage
 - b. Automated workflows will be vast improvement
 - c. Automating workflows forces companies to examine how they work
 - d. More rigid and consistent workflows from PDM
 - e. Automation saves so much time, but size and complexity of PDM should scale with business needs
 - f. Test load server to minimize errors
 3. History & current characteristics
 - a. Initial PDM was homemade, reflection of old paper system
 - b. PDM used to be about the basics, not integrated
 - c. Lack of discipline in file management before PDM
 - d. No PDM means more errors and slower times
 - e. PDM helps with configurations
 - f. Product complexity affects need for PDM
 4. Dealing with exceptions & problems
 - a. Problems when not everyone can access the right data they need
 - b. Handling exceptions, especially in configurations
 - c. Creative people can find solutions within PDM
 - d. Adding PDM to an already stressed network can cause problems
 - e. Adding PDM into mix breaks existing associations, must be rebuilt
 5. Centralized storage
 - a. Centralized storage and check in/out

Investment in PDM

1. Improving the system
 - a. Wanting to improve the system is costly
 - b. PDM as something not invested in frequently
 - c. No more time or resources for robust PDM development
 - d. PDM must be viewed as an improvement that's visible
 - e. Leadership in smaller business has bigger affect on PDM implementation

- f. When things are busy, process and system improvements aren't priorities
- g. Tackling PDM during slower economy
- h. Larger corporations probably don't invest in PDM with slow economy
- 2. Investing to change software code vs. changing processes
 - a. How to adapt system to existing processes?
 - b. Change software, or people?
 - c. Changing systems and software can be difficult
 - d. Starting fresh with PDM, no prior design history works well
 - e. Change process and format vs. write more translation code
 - f. Try not to write custom code for exceptions
 - g. Last resort is to write custom code, hard to maintain
- 3. Investment & money concerns
 - a. When possible, measure how PDM affects budget
 - b. PDM must be well budgeted and planned for
 - c. ROIs are great
 - d. No extra investment in CAD seats
- 4. Software vendor concerns
 - a. Companies try to stay under single vendor – it's easier, but not always the best choice
 - b. Depending on CAD, other software packages may have better analysis tools

How people & PDM interact

- 1. Concurrent engineering & Organizational change (brought on by PDM)
 - a. PDM merely enables innovation
 - b. Over the wall engineering
 - c. Group information together up front, forces concurrent engineering
 - d. Forces concurrent engineering
 - e. Formalize concurrent engineering in management scheme
 - f. Focusing too broadly on product stifles concurrent engineering
 - g. Organizing into zones discourages departments
 - h. Defining processes during PDM implementation (not before) is an SME advantage
 - i. PDM is no longer just an IT affair
 - j. PDM is no longer just administrative in nature, it's becoming integral
 - k. Going from paper to digital system has been difficult
 - l. Firefighting and problem solving constant
 - m. Chaotic organization, fears, have hindered implementation
 - n. Sometimes having outsiders with new ideas helps
 - o. Getting engineers used to using the PDM
 - p. Trying to do old processes inside PDM at first
 - q. Eventually engineers change their habits
 - r. Implementer becomes face of PDM

- s. Must be committed to change, or else failure
 - t. Engineers can do more engineering work
 - u. Interface merges many types of data
 - v. In large corporations, small siloed systems could probably be easy to start using
 - w. Company culture may become an issue
2. Expectations of system
 - a. Expectations of system
 - b. Manufacturers shouldn't be doing most software development
 - c. Companies making software for products may think they can make PDM well too
 - d. Managing scope is important
 - e. Systems for dealing with exceptions before PDM
 - f. Manual process sometimes can't be avoided
 - g. Looking up old stuff reminds that it's not good
 - h. Design engineers using PDM a lot more than before
 - i. Either people love the PDM or hate it depending on how it's working
 - j. Data entry is annoying, retrieval is great
 - k. Resistance to PDM is futile
 - l. Explaining basic PDM concepts to laypeople is still hard
 - m. Easy to use and understandable interface
 - n. Siloes of data won't be a huge concern
 3. Restricting the environment, but also errors
 - a. Rigor of PDM prevents errors
 - b. PDM is positive, but strict
 - c. PDM can sometimes be too restrictive
 - d. Engineers feel constricted by the PDM at first
 - e. More rigor required, but less rework or wasted work
 - f. Less rework being done
 4. Needed background knowledge
 - a. Engineers interact with and depend on PDM more than ever to do their jobs
 - b. Importance of database knowledge in design process and understanding PDM
 - c. Database basics are important because of the level of ubiquity in the engineer's job PDM has
 - d. Data relationships becoming as important as engineering math skills
 - e. Demographics of aerospace is getting older

Managing PDM

1. IT vs. Engineering, what career paths does this create?
 - a. No longer handled by traditional IT group
 - b. Separate organization dedicated to PDM
 - c. ERP can fail outside IT

- d. People are making careers out of PLM, not IT or engineering
- 2. Quality concerns
 - a. Not visible to customer = not high quality
 - b. PDM and quality control are hard to mix

Measuring PDM

- 1. How much is budgeted for it
 - a. Integrate data requirements into project management activities
 - b. When customer pays for design and tooling, costing everything gets rolled together
 - c. PDM is hard to measure
 - d. Planning for PDM beforehand
- 2. Its effect on organization
 - a. Verified it satisfies customer's requirements
 - b. PDM affects the end product majorly, but that's hard to see
 - c. Model based environment provides many benefits

Appendix D. Contact Forms for Survey Participants

Survey Contact Email

Subject Line: Engineering Data Management and Small Manufacturers – Survey for University Research

My name is Karen Waldenmeyer, and I am a graduate student working on my master's thesis entitled: "The Small and Medium Enterprise's Perspective of Product Data Management," under the direction of Nathan Hartman at Purdue University (NHARTMAN@PURDUE.EDU, 765-496-6104). My research is focused on how small and medium manufacturers tend to view, use, and manage product data, usually using engineering design systems.

To accomplish this goal, I would appreciate if you, or someone else in your company who is knowledgeable about your engineering design process could fill out a short online survey relative to this topic, in the next few days is possible. Please forward this survey to anyone in your organization who has knowledge of the engineering design process. The survey will consist of questions about your impressions of product data management and engineering design systems and how they have affected your company. This survey should take approximately 10-20 minutes, and is voluntary, anonymous, and participants can stop at any time if necessary. No identifying information will be collected about you, or your organization. All participants must be age 18 or older.

All procedures and questions have been screened and approved by Purdue's Office of the Vice President for Research's Institutional Review Board for research involving human subjects.

Please click the following link which will take you to Purdue University's hosted survey site which has been constructed and administered by myself to collect information to identify specific strengths and weaknesses small manufacturers face when managing product data, and make recommendations for how to address these characteristics. The goal of this survey is to call attention to the unique qualities of small US-based manufacturers and how we can best improve engineering information technology conditions for these businesses, regardless of product or situation.

Please click here:
[QUALTRICS LINK GOES HERE]
to begin the survey. Please complete the survey as soon as possible.

Feel free to contact me at 574-514-6229 or KWALDENM@PURDUE.EDU if you have questions or concerns regarding this online survey.

Thank you for your time!

Karen Waldenmeyer
Graduate & Research Assistant
Computer Graphics Technology, Knoy Hall
Purdue University, West Lafayette, IN
KWALDENM@PURDUE.EDU
574.514.6229 (voice)

Nathan W. Hartman, Ed.D.
Department of Computer Graphics Technology
NHARTMAN@PURDUE.EDU
765.496.6104 (voice)

Survey Reminder Email (text), to be mailed one week after initial email

Subject Line: Engineering Data Management and Small Manufacturers –
Survey for University Research, Reminder

Approximately a week ago, you received an email request to participate in a Purdue University study about how small and medium manufacturers have experienced product data management software as a tool to aid engineering design. If you already completed the survey, **thank you very much! Your participation is greatly appreciated.** If you have not already participated, please do so at your earliest convenience.

Again, the survey will consist of questions about your impressions of product data management systems and how they have affected your company. It should take approximately 10-20 minutes, and is voluntary, anonymous, and participants can stop at any time if necessary. No identifying information will be collected about you, or your organization. All participants must be age 18 or older.

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Thank you for your time!

Karen Waldenmeyer
Graduate & Research Assistant
Computer Graphics Technology, Knoy Hall
Purdue University, West Lafayette, IN
KWALDENM@PURDUE.EDU
574.514.6229 (voice)

Nathan W. Hartman, Ed.D.
Department of Computer Graphics Technology
NHARTMAN@PURDUE.EDU
765.496.6104 (voice)

Appendix E. Survey

Are you age 18 or over?

Yes/No

If No Is Selected, Then Skip To End of Survey

Q1

What industry is your company in?

- * Aerospace
- * Defense
- * Industrial Equipment
- * Automotive
- * Consumer Products
- * Medical
- * Other (specify)

Q2

Approximately how many people does your company employ?

- * < 10 people
- * 10 - 49 people
- * 50 - 99 people
- * 100 - 299 people
- * 300 - 499 people
- * 500+ people

Q3

How many locations does your company do engineering design?

- * One location
- * More than one location

Q4

Is your company an original equipment manufacturer (OEM), supplier only, or both supplier and OEM?

- * Original Equipment Manufacturer
- * Supplier Only
- * Both OEM and Supplier

Q5 (if Q4=OEM)

If OEM, do you buy parts from one supplier or many?

- * One supplier
- * Many suppliers

Q6 (if Q4=Supplier)

If supplier, do you supply to one OEM or many?

- * One OEM
- * Many OEMs

Q7 (if Q4=OEM)

What do you buy?

- * Engineering design only (you pay someone to design the part but make it yourself)
- * Manufactured parts designed by someone else (you buy parts that were designed and manufactured by someone else)
- * Manufactured parts only (you design the part, but pay someone else to make it)
- * Some other situation (please explain)

Q8 (if Q4=Supplier)

What do you supply?

- * Engineering design only (you don't make the part, only design it and give the design to OEM to make)
- * Designed and manufactured parts (you design the part and manufacture it yourself, then sell it)
- * Manufactured parts only (customer gives you design, and you make the part for them)?
- * Some other situation (please explain)

Q9

What format does your company typically use to define engineering design?

- * 3D CAD tools
- * 2D CAD and drawing tools
- * Other (specify)

Q10

Does your company have a digital system set up to handle engineering design data specifically? (You may call it a database, an engineering design database, a product data/lifecycle management system, or something similar).

- * Yes
- * No

If No Is Selected, Then Skip To End of Survey

Q11

Rate your level of involvement with engineering design systems in your company.

- * Never Involved
- * Slightly Involved

- * Somewhat Involved
- * Very Involved
- * Extremely Involved

Q12

Which general areas of engineering design do you use your system for?

- * General repository for data that is controlled
- * Versioning and access control (Check in & Check out)
- * Product structure management (Bills of materials)
- * Engineering Change Management
- * Configuration management
- * Manufacturing information management
- * Other (specify)

Q13

When does your company enter engineering information into the system?

- * As much as possible all at the beginning
- * Shortly into the design process, then start entering data
- * Halfway into the design process, then start entering data
- * Design process is almost over before entering data
- * Design has ended, then we enter the data (using system mostly for archival)
- * Other (specify)

Q14

To what extent do you use workflows in your engineering design system?

Workflows are a term for directing work from one person to another for approval, validation, and design changes.

- * Don't use workflows
- * Use workflows once in a while
- * Use workflows sometimes

- * Use workflows frequently
- * Use workflows extensively

Q15

Rate the effect the engineering designs system has on the time it takes to complete a design task (a design change, configuration, new part, etc).

- * Makes tasks much slower
- * Makes tasks slightly slower
- * No effect on time to do tasks (Neutral)
- * Makes tasks slightly faster
- * Makes tasks much faster

Q16

Rate the effect the engineering design system has on the time it takes to find information to complete a task.

- * Makes finding information much slower
- * Makes finding information slightly slower
- * No effect on time to find information (Neutral)
- * Makes finding information slightly faster
- * Makes finding information much faster

Q17

Does your engineering design system share data with other parts of the business beyond engineering?

- * Yes
- * No

Q18 (if Q17=Yes)

Which parts of the business share data with the engineering design system?

- * Ordering

- * Purchasing
- * Manufacturing
- * Finance
- * Human Resources
- * Other (specify)

Q19

How often do you exchange engineering data with your suppliers and/or customers?

- * Daily
- * 2-3 Times a Week
- * Once a Week
- * 2-3 Times a Month
- * Once a Month
- * More than a month goes by between exchanges
- * Never

Q20 (if Q19 does not = Never)

What is the nature of this data exchange?

- * OPEN RESPONSE

Q21

Do you have your engineering design system set up to communicate with a customer/supplier's engineering system directly?

- * Yes
- * No

Q22 (if Q22=Yes)

Please rate the level of automation of this communication with the customer/supplier's engineering system.

- * No automation
- * Slight automation
- * Some automation
- * A lot of automation
- * Complete automation

Q23

To what degree do you use neutral file formats to exchange models or drawings?

2D file formats: .DXF, .DWG, others. 3D file formats: STEP, IGES, others

- * Never use neutral formats
- * Infrequently use neutral formats
- * Sometimes use neutral formats
- * Frequently use neutral formats
- * Exclusively use neutral formats

Q24

Who is your engineering design system managed and maintained by?

- * IT organization
- * Engineering organization
- * Other (specify)

Q25

How often does your business invest in upgrading and maintaining the engineering design system?

- * Every 6 months
- * Every year
- * Every 1-2 years
- * Every 2-4 years

* 5 years+

Q26

How does your company monetize their engineering design systems?

* OPEN RESPONSE

Q27

Does the software you use to do design (3D, 2D), analysis, engineering data management systems, tend to come from the same software vendor, or from different vendors?

* Same vendor

* Different vendors

Q28

What is the procedure for solving a problem if an error or issue is encountered in the system?

* OPEN RESPONSE

Q29

Do you feel your engineering design system has contributed to concurrent engineering?

* No contribution

* Small contribution

* Moderate contribution

* More than average contribution

* Ample contribution

Q30

Do you feel your engineering design system restricts the way you would like to do engineering design?

- * No restriction
- * Slight restrictions
- * Moderate restrictions
- * Many restrictions
- * Most restrictions

Q31

Does your engineering design system meet your expectations for what it should be able to do?

- * Meets no expectations
- * Meets few expectations
- * Meets some expectations
- * Meets many expectations
- * Meets all expectations