Implementing a PDM Installation and Migrating Data in a PLM Environment

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ABSTRACT- *The goal of this study was to gain an understanding of how companies in various industry sectors handled the migration of product data and the implementation of a PDM tool within the scope of a larger PLM environment. Ten companies were examined regarding their implementation process relative to PDM and PLM toolsets. Relevant sources from within each company were interviewed to gather information in a long interview format. Results from these companies are detailed in aggregate form within the body of this paper. Information was collected according to four different areas: PLM implementation timelines and mitigating factors, chosen PLM toolsets, data archival and migration strategies, and training. Conclusions are made in the final section relative to industry and engineering design graphics curricula.*

I. INTRODUCTION

In the design of complex products, a variety of data exist from multiple disciplines, which at times makes digital communication and collaboration difficult within a design environment. Making data and information available to those that need it, when they need it and in an accurate fashion are critical. This typically includes information from planning, design engineering, job costing and production all coming together through a variety of software programs and platforms: CAD systems, various databases, mainframes, minicomputers, workstations, PCs, and all operating systems that this may entail (Dickerson, 1997).

As CAD systems developed and became more sophisticated, there was a need to manage digital models and drawings, just as their paper-based counterparts had been managed in the past (Foster, 2001). However, due to the dissimilarities in much of this data, this task was not as simple to accomplish as first thought. Companies did not always use the same CAD, analysis, or manufacturing software, nor did they always update that software according to similar schedules. In doing so, they created scenarios where eventually certain parts of their global businesses could no longer communicate with each other. To address this issue, companies invested in product data management (PDM) systems to manage this data. "Product data management has proven its value as a critical tool in handling the enormous amounts of technical information companies generate" says Ed Miller, the president of CIMdata Inc., a firm in Ann Arbor, MI., which provides consulting services, market research and reports, education, and conferences focused on product-data management and computer-aided design and manufacturing systems, technology, and applications (Miller, 1998).

PDM has also provided the basis for Product Lifecycle Management (PLM). PDM supplies the core functions that create and deploy successful PLM strategies; therefore growth in the PLM market directly expands the opportunities in the PDM market. The overall PLM market in 2002 was up slightly compared to 2001 at approximately $13.5 billion, with 33% of that total defined by to collaborative product definition management (CPDM). "While the tools segment remained flat in 2002 at $9.3 billion, CPDM grew by 8% to reach $4.2 billion" (Amann, 2004). According to Daratech Inc. (2004), the acceptance of PLM as a business strategy in the manufacturing and design sector will increase the need for PDM and related technologies (ProE Community, n.d). Daratech's August 2004 technology assessment predicts that end-user spending on product data management technology is expected to increase a moderate 1% in 2004 to $1.73 billion, but is projected to rebound strongly in 2005. Eventually by 2008, end-user spending on PDM technologies will expand at a compound annual growth rate of 12% through 2008 (Daratech, 2004). These statistics suggest the adoption of a set of tools that will have an impact on how engineers and designers, as well as managers and production analysts, communicate within the company of the future.

However, these systems are typically created by the same vendors that develop CAD systems, which means that companies are being forced to use the same tools from one vendor or a few vendors due to the inherent inability of differing vendors' systems to communicate with each other. This also means that a company's options for organizing, managing, and archiving their product data are limited to that vendor's toolset. To change vendors in an effort to find a better price or better technology often means losing functional access to years or decades worth of CAD models, drawings, analysis files and manufacturing plans, because the new system could not read and interpret a company's legacy data. Given this potential loss of millions of dollars and countless hours of time, the product design and discrete manufacturing companies of the world have continued to invest in CAD and PDM technologies at a steady rate. However, this investment is not without consequence. The dynamics of selecting and implementing PDM tool sets, as well as migrating from one tool set to another, has become an every-day issue to the engineering staff that is expected to use these tools in the design of their products and to the IT staff that is hired to support and facilitate this process.

II. METHODOLOGY AND PARTICIPANT DESCRIPTIONS

In an effort to better understand the selection, implementation, and migration of PDM data and tool sets within a corporate environment, ten (10) companies were selected to participate in this project. They are all U.S. companies, although all of them have multiple divisions within this country and abroad. The participant companies represent the following product sectors: aircraft manufacturing (commercial, corporate, and military), aircraft engine manufacturing, heavy equipment, agricultural equipment, automotive manufacturing, automotive manufacturing suppliers (Tiers 1 and 2), and aerospace defense. These companies were selected based primarily on their ability to represent the collaborative environment necessary to derive full benefit from a PDM system. They were also selected based on their size (workgroups and numbers of corporate divisions) and their availability and willingness to participate.

Given the open-ended nature of selecting, implementing, configuring, a PDM system within a large environment and migrating data between systems, a long interview format was chosen to gather information relative to these companies. Long interviews comprise one of the major knowledge elicitation methods in an exploratory study (Creswell, 1998; Moustakas, 1994; McCracken, 1988) and for acquiring knowledge and information from assumed experts in a given discipline (Firlej & Hellens, 1991; Cordingley, 1989; Olson & Biolsi, 1991). The term “interview” in this sense is meant to describe a technique and not an event. In an interview, the researcher asks a person with domain knowledge specific questions related to that domain in an attempt to gain insight into concepts that are not readily available (Cordingley, 1989). Interviews potentially allow for a great deal of expansion on the part of the participant depending on the type of interview that is conducted, although the researcher generally approaches the situation with some type of guide so as to avoid becoming disorganized. Cordingley (1989) also suggests three styles: structured, semi-structured, and unstructured. The semi-structured interview was the method used for this study. It combines the structure of a few prepared questions, but it does not require the researcher to ask them in a specific order and gives the liberty to add or remove questions as necessary. In this research study, participants at each company were selected based on their knowledge and experience with their company’s specific CAD, PDM, enterprise resource planning (ERP), and manufacturing data systems, as well as the implementation and configuration strategies and plans surrounding these systems. Typically these were people that held managerial or senior staff positions in engineering and/or IT departments.

The interview questions were developed according to the structure of PDM applications suggested by Cornelissen (1995): structure management, retrieval management, release management, change management and work flow management. In addition, the interview format also gave the researchers the opportunity to probe deeper into the reasoning behind the selection of a particular strategy or decision. The interview guide consisted on twelve questions that covered the following four major areas: PLM implementation timelines and mitigating factors, selected PLM toolsets, data archival and migration strategies, and training. Table 1 at the end of this paper includes the specific interview questions. Through conversation analysis suggested by Creswell (1998), Cordingley (1989), and Olson and Biolsi (1991), the transcripts of the interview notes were analyzed for common terms, attitudes, experiences, and themes between the participating companies. The commonalities (and a few differences) between the companies relative to the selection, implementation, and migration of PDM tool sets within a PLM environment are presented in the next section.

III. FINDINGS

PLM Implementation Timeline and Mitigating Factors

The data gathered from the companies yielded information that all of the PLM implementations were first with CAD technologies, later with PDM technologies, and finally with global enterprise wide PLM technologies. In all instances the first tools used in the PLM implementation were the CAD tools and once it was realized that there were going to be massive amounts of digital data developed that had to be secured, stored, and able to be retrieved for reuse then software tools were developed to accomplish these tasks. Finally as computer hardware became extremely powerful and economically feasible for implementation at the desktop level and software tools matured, coupled with the growth of the Internet, global enterprise wide PLM technology adoptions became widespread.

These implementation scenarios are typical representations of how PLM was initially developed, and it leads directly to the challenges that corporations face today with multiple data sets for product data. Typically CAD legacy and related product data, and data stored in PDM systems, can not be easily and economically moved into a new PLM tool without having to make decisions on which files and how much of the existing data should be moved. One purpose of this study was to determine the strategies and mitigating factors that different companies used to determine the existing product data to be moved into the new PLM system and the data to not be included in this migration and a rationale for why these decisions were made.

The adoption of the CAD, PDM, and related product data tools varied between different corporations based on the products that they manufactured. The adoption of PLM tools can be classified as corporations who were "early adopters" and corporations who were "followers." The early adopters were corporations that typically had the economic means or government support through defense contracts to adapt new technologies and help in their development. In the companies that were interviewed for this study all of the early adopting companies were aircraft OEMs. The rest of the companies interviewed were followers who typically did not have the economic means to implement these technologies or they wanted to see how successful the implementation of these technologies was before they began to use them.

One of the first CAD systems adopted was Computer Vision (CV) and this occurred in the early 1980's with an aircraft manufacturer. The CV software ran on a dedicated minicomputer. Although it was a cutting edge system at the time, its main drawback was that the minicomputer that it ran on could only be used to run CV. These systems were very expensive, and because they had to be dedicated to CV use, they were soon deemed to be not cost effective because of their inability to do more than just run CAD software.

The second major technological change occurred when CAD technologies were developed for mainframe computers to run CAD systems such as CADAM, CADDS, CATIA and Unigraphics. The early adopters of this technology on a large scale for the most part were the aircraft manufactures. The mainframe systems allowed the companies to be able to use the hardware for multiple functions outside of CAD and it also allowed multiple users to be able to use the hardware. Thus, mainframe CAD systems quickly replaced the dedicated CV workstations with specific manufacturers. The mainframe computers made sense from a business standpoint but from a CAD production standpoint they were cumbersome and slow. The mainframe computers for production CAD were inefficient because very complex parts and assemblies with large file sizes could not be handled by the mainframe computers. This lack of machine performance coupled with the very high cost of mainframe computers forced both manufactures and CAD software companies to seek alternate hardware platforms.

The cost and inefficiencies of mainframe computers for operating CAD software lead vendors or the participating companies themselves to develop the CAD software for use on UNIX workstations. The UNIX workstations were more cost effective so more engineers would have access to the CAD software within these participating companies. However, the initial problem with UNIX workstations was that they were not powerful enough to handle the demands of complex CAD files and assemblies so the productivity gains were not immediately available. But as the UNIX workstations became more powerful and more economical, there was wider integration of UNIX based workstations with CAD and analysis tools into engineering. With the greater use of CAD software, more CAD and product data files were developed and had to be stored.

The amount of CAD files used to develop complex products such as airplanes and automobiles led to the initial development of product data management systems. Like CAD technologies, the initial development and implementation of PDM technologies was done by aircraft manufactures. According to the participating companies, the PDM technologies they initially invested in were rather cumbersome, but they eventually improved with a great deal of cooperation between the software vendors and their corporate clients. This process typically began in the late 1990s with software such as I-man, Pro/PDM, Intralink. More current installations have begun in the early 2000s, and have focused on tools with more of a PLM focus: TeamCenter, SmarTeam, ENOVIA, and Windchill.

The time frame for the implementation of these tools, from the stand point of both initial implementation and ongoing support, all participating companies agreed that this is a never-ending process. They stated that their integration of these tools into their corporate processes typically began with the launch of the various technologies, and that it would progress in cycles. Each of these cycles would last anywhere from one (1) year to five (5) years. One company even said that their integration process has occurred periodically over the course of eighteen (18) years, with their most recent push in February 2004. There have been several factors that have contributed to this cyclical, ongoing process of defining the scope with which these tools would be implemented within the various organizations.

One of the primary reasons for the extensive timeframe for implementation was the maturity of the software tools themselves. Each participating company experienced a scenario where they were in a "developmental" relationship at some point with the software vendor. This caused them to take a "wait and see" approach towards a full-scale rollout of the technology. The companies (even the early adopters) could not take too much of a risk in staking their product design process to a tool that was still underdeveloped. On a positive note however was the promise of the ability to share data within and between the design groups in the participating companies, which in some cases offset the risk of immature technology.

Another significant factor that impacted the timeframe of implementation was corporate vision, and tied to this was a mapping of the technology to business processes (or lack thereof), a corporate-level champion to support the implementation, and training of personnel. Training will be discussed later in this report, but in some cases, it was a stumbling block to implementing PLM technologies. Several participating companies had elaborate strategies for mapping the PLM technologies to their business processes, which typically centered on their engineering design and data releasing process. All companies identified the importance of a corporate champion – someone has to communicate to the masses, show a positive spin on the tools as they relate to business strategies and profits, supported the development of a training plan to bring people up to speed, and when required forced resistive groups or individuals to adopt the new technology. Related to these factors is corporate culture. All companies indicated that through the corporate champion it is important to establish a culture of change and technology acceptance within the organization. These tools will change the way a company operates, and the personnel must be ready to accept (or at least deal with) these changes or the implementation will be unsuccessful. Finally, most participating companies expressed that when they first started the implementation process they had little or no idea how these tools should be installed or configured. They relied heavily on software vendors to help them adapt these tools to their processes. This relationship often led to mixed results as will be explained later in this report.

Of secondary concern to the participating companies were other factors that did not necessarily have a great impact on the process by themselves, but they did have an impact when combined with the aforementioned issues. Their expertise with using the various systems, especially the PDM tools, was typically lacking in the beginning stages of the project. Even though several companies had mapped out rather elaborate strategies for moving their data, not all possible scenarios could be reasoned out or practiced. Each company generally stated that allowing some amount of flexibility in the implementation process is crucial. Customer requirements were also an issue that arose for some companies. These companies had been sharing data with customers in the form of drawings or web-based documents, which now had to pass through the PDM system in order to be tracked and archived. This now required their customers to have some type of accessibility to this information, which was an IT struggle at first. In order to overcome this, those affected companies implemented several of the PLM tool vendor's web technologies for data access by customers. Finally, project funding was an issue for all participating companies. Due to the length of time taken for each implementation stage, and the direct effect on day-to-day business processes, a consistent level of funding was critical, but rarely achieved. For those that did have consistent funding, the corporate-level champion was critical in securing it, and for those that did not, they cited the lack of a strong corporate-level champion as one of the reasons that funding was inconsistent.

PLM Tool Sets – Past and Present

As in most companies, it can be assumed that manual methods engineering graphics methods were used at some point – indeed some more recently than others – to design and document their product development process. However, that is not necessarily the focus of this section of the report. The focus of this section is an overview of the CAD/PDM/PLM toolsets that the participating companies most recently implemented, the toolsets that they moved away from, and the strategies employed for handling the legacy data once the move was completed.

The movement away from an existing software toolset or manual process to the current process and set of tools is characterized by these companies' move towards "the big three": CATIA, Unigraphics, or Pro/ENGINEER and the associated technologies that surround those brands. Generally speaking, each company migrated at some point from a manual drafting environment, to a 2D CAD tool or a wireframe 3D CAD tool, and finally to solid modeling. With that migration, there came a large set of data that had to be managed, which led most companies to adopt some type of PDM system. As business processes developed to embrace these tools, and the economy became more globally competitive, the participating companies saw the need to move to a more integrated set of tools. This was evidenced by the movement away from a mixture of internally developed tools and commercially developed tools to an integrated solution provided by one (or a small number of) vendors. Tables 2 and 3 at the end of this paper summarize the toolsets being used currently, and in the past, by the ten participating companies.

As can be seen from the summary in Tables 2 and 3, some companies moved from the same vendor's tools to another version of those same tools, while other companies moved to a new vendor's tools entirely. Undoubtedly there were several issues that arose during these implementation processes. The remainder of this section of the report will detail those issues. In addition, it will describe how the participating companies have either continued to use their legacy PLM toolsets or how they have phased them out.

For those companies that did change vendors during their implementation of a new PLM toolset, the reasons that arose for the change were wide-ranging without an implicit theme. However, if one could attempt to draw an inference from the disparate responses, it might be that the companies thought that moving to the new toolset would improve their productivity or their product. Two companies did state that the high cost of maintaining internally developed tools was a leading cause for the change in toolsets. Similarly, one company stated that the cost of their vendor-supplied legacy tool was becoming too great. Two other companies also stated that their corporate entity dictated the change. One company stated that the move allowed them to discontinue their mainframe installation and with hardware that was faster and more cost effective. The issues that surfaced during this process typically centered on lack of data preparation and file management and the inherent tedious and cumbersome nature of changing and entire set of engineering tools. Other issues that were exposed also included (perceived) loss of accuracy of CAD data when it was translated, ineffective support and processes suggested by the vendor, and inexperience with high-end systems on the part of the IT staff.

For those companies that did not switch vendors, but simply updated to a newer version, the common theme that emerged from their responses centered on accuracy of data (or the perceived lack thereof). All of these companies had difficulties in getting their CAD data, and its associated metadata, to accurately translate from one CAD tool to the next, or to accurately populate their PDM system upon import. Their strategy to address these issues was to only import small groups of files at any given time, or to re-model the geometry. While this sounds less than appealing, it was their only effective strategy. In a similar vein, one company did not necessarily have issues with their data, but they had issues with the custom interfaces they had written between their various tools. When the tools were updated, the interfaces had to be updated as well. A common solution to resolve these problems that all companies suggested was to implement a testing protocol for your specific situation and follow that rigorously, regardless of any objections to the contrary. Companies in this group also had personnel issues that arose during the upgrade which generally centered on people not following corporate standards and getting everyone trained in a timely fashion. They also suggested that once a person learns the new tool they should not be allowed to use the old toolset unless absolutely necessary. Another problem occurred when interfacing with a company's customers or suppliers. There were instances, especially with suppliers, when the change in a CAD or PDM tool led to interoperability problems with outside corporations.

Each participating company was also asked if they continued to use their legacy PLM toolsets, and if so how they planned to disengage from using them at some point in the future. One common theme that came out of this portion of the study was that there was typically no "cold turkey" event where the old system was shut off and the new system was turned on. Each company typically maintained their legacy system for at least a few months if not longer. In five out of the ten companies, they have had to continue to maintain their legacy tools due to industry or governmental regulations, which will likely force them to continue for several years. In the other companies, their legacy systems were not simply "cut off" – they were phased out over time. This "phase out" period often coincided with new product releases or other business changes which will be further discussed in a later section of this report. It also typically involves only converting the data that is necessary for use in new or modified products. The primary lesson learned is to establish a known, commonly accepted timeline for moving away from the legacy toolset and communicate this timeline to all concerned parties, and stick to the plan. Only deviate from this plan when business reasons dictate doing so.

Data Archival and Migration Strategies

Data archival was critical for the participating companies in this study. All of the companies design complex products with hundreds (if not thousands) of parts which have to be accessible by people within the organization or business partners on a regular basis. In some cases, this period of accessibility can last for decades instead of simply months. Due to the accessibility and chronological issues, most of these companies spent considerable time and effort to develop an archival process and set of permissions for this data that would serve their organization with the minimal amount of inconvenience. For all of the companies involved, there was typically a decision made regarding the existing data for their products, and three general categories were made: released (current), future, and service. The data that was included in the service category was typically left as legacy data, and it remained either in the former PDM system for a specific time, or it was imported into the new PDM system with little or no metadata associated with it. If it was necessary that any of the legacy data be accessed for released or future products, it would be edited or re-modeled as necessary and archived with the released (or future) data within the PDM system. The data labeled as released or future was typically migrated into the current database instances of the PDM tool, and if there were any errors, they were corrected or the object was typically re-modeled as a last resort.

In order to add structure to the PDM instances, the companies organized their data either by product (or project) or by functional group as it related to the product. Each company organized their personnel a bit differently, but they were generally organized according to the product they worked on or by their job function. This schema for the data and for personnel was combined, typically by the engineering IT staff, into a set of permissions and accessibility rules that determined which individuals or groups could access the data, and how much authority and control they had over this data. However, the IT staff did not make this decision unilaterally – each company stated that there was a fairly elaborate process for drawing consensus on the implementation of the new PLM tools. The process basically centered on the formation of an advisory group that included members of each workgroup to be represented, which was usually engineering, design, checkers, manufacturing, procurement, service, and management. While the individual companies' processes looked slightly different, this was the general summary of the groups that were included.

An advisory group typically began the data archival and migration procedure by examining the current product releasing process and determining how it mapped to the new toolset. In some cases, it was quite close, but in other cases, companies changed their entire process to accommodate the new toolset. They found this to be easier than trying to customize the tool. While this initially was met with resistance, it was quickly discovered from the never-ending issue of service releases by the software and hardware vendors that any custom programming or routines put in place would have to be edited each time anew release was issued. Many times customization was not cost effective and the future return on investment forced processes changes. The typical product data releasing process that emerged for a majority of the participating companies was some form of the following stages: development, design, testing, tooling, production, service/maintenance, and obsolete/archived.

The aforementioned information dealt with the procedural nature of day-to-day operations and usage of the new toolsets. But what about the actual process of migrating the data from one system to another? This process typically coincided with a strategic business decision on the part of the participating companies. Indeed, every participating company reported that their decision to move to a new toolset was based on the new functionality presented by the software or the desire to gain market share based on the perceived potential performance improvement to be had by the implementation of the new toolset. In one company's case, it was actually dictated as a corporate objective to migrate to best-in-class technology. Once the decision to change toolsets was made, eight out of ten companies decided it was best to designate a new product or a major revision of an existing product as the forum in which to roll out the new tools. When asked why this was the case, the general response was that the new product was "high profile", it "had resources" devoted to it, and that the best users of the tools were often associated with that project. However, there were procedural issues to be addressed at this level as well. The migration did not occur all at once. Each company moved small amounts of data at a time (usually around 10% or less of their files at a time), although some companies did try to migrate entire directories into the new system, which worked with mixed levels of success. In the end, it was a matter of proceeding in manageable chunks as opposed to moving all the data at once. Another issue was sustainable funding. Budgets were large in the beginning, but as other business needs became more pressing or results were not seen quickly enough, money was moved from the project and manpower was shifted. In some cases, this was not a problem, but two companies noted that this brought their migration process to nearly a crawl, and the entire process took nearly twice as long as originally planned. A third issue that was encountered during file migration was a difference in the way a newer version of software processed header and metadata information within a file. This caused two companies to develop some form of customized script to move the data between the systems. While this was not an ideal situation, it did work, but the script was not maintained after the migration was finished. In all, the participating companies moved tens of thousands of files this way, which totaled five to six terabytes of data in some cases.

Personnel Training Issues

It was deemed critical to answer questions about budgetary and process-related issues when it came to making sure that engineering personnel knew how to use the PLM toolset. There are countless horror stories about training programs that were implemented to train individuals how to use new hardware and software tools which failed miserably due to poor planning and insufficient funding and support, as well as failure on the part of the tool vendor to live up to promises made during the sale. This section outlines the participating companies' responses to training issues.

It is typically difficult to decide how many people should be trained to use the new toolset, as well as which groups receive priority within that training process. For each of the companies that participated in this study, priority was typically given to those people in their company designated as "engineers", "designers", or "modelers". This was due to these people's first-hand use of the tools to perform their daily job functions. Secondary consideration was given to those groups designated as "manufacturing", "tooling", or "management". The range of people trained by these companies is quite large, which is due in part to the entities that actually participated in the interviews. In some cases, it was only a large division of a much larger company that was participating, as opposed to the main engineering group within a large company with no divisions. Taking that into account, the number of people involved in training was between approximately 60 people to 2500 people depending on the company. A common response was approximately 400 to 600 people, who were typically labeled as "engineering" or "design" personnel.

With this amount of people being trained, it is crucial to archive and record the data they are creating accurately and make it available to others within the organization. When asked if they had a 1 to 1 ratio of PDM licenses to CAD licenses, only two (2) companies responded that they had such a ratio. The other eight (8) companies responded that they had more PDM seats than CAD seats. The rationale behind this decision is that they typically saw the PDM tool as more than just a CAD file manager. It was being seen as the crucial entry point for most (if not all) of their engineering-related data, which included analysis, tooling, manufacturing, purchasing, and customer service. One company even expected to have a future ratio of four (4) PDM licenses for every one (1) CAD license within their organization. From this, it can be seen that a significant reliance upon the PDM system is emerging within these companies that participated in this study.

The final issue pondered by these companies related to training was whether to use vendor training or in-house training. The responses reflected a mixture of these types of training once the new toolset was chosen and implemented. The mixture that each company chose also had a significant effect on the overall training budget that was used for the implementation. One company actually convinced management to fund the PDM migration project based on the fact that they would conduct all in-house training accompanied by vendor-supplied self-paced learning tools, and that this would yield a significant savings in the overall project cost. However, the other nine companies typically used a mixture of instructor-led vendor-supplied and in-house training classes. Most people were initially trained in the basics of the CAD and PDM tools. Afterwards, a selected set of people went for more advanced training or more job-specific training. It was during the latter when these companies often collaborated with the vendor to develop company-specific training materials, or they gained permission from the vendor to modify the default training offering to fit their internal processes. The companies found this to be critical in the effectiveness of the training programs for the new toolsets. If the various constituents went through generic training, it would be very difficult for them to complete their job tasks since each company has a particular process for utilizing the PLM tools.

Overall, nine (9) out of ten (10) companies spent anywhere from hundreds of thousands to millions of dollars on training, which was directly affected by the number of people trained and the types of training chosen. The more specific a training program became, the more it would cost. This issue was central to the basic sentiment by most of the companies when they said it was important to find a balance between those people that need to be trained and what is critical for the project. It was not feasible to train everyone, but it was critical to choose the right people to be trained. In most cases, the companies expressed that there was not a common process for determining the training budget – some simply had no idea how it was determined, while others simply multiplied the number of courses to be taken by the dollar amount charged for each one. Regardless of the method, most companies indicated that the budget for training seemed to be low, which meant that not all training could be completed and they had to resort to internal or informal training alternatives. Some established mentor programs, and others had informal "lunch and learns" seminars to share information. These final two approaches actually helped to alleviate one of the major concerns that each company had during training – how do you get everyone trained and still get work done at the same time. In summary, each company indicated that it was critical to make sure that the training budget was spent correctly by analyzing training needs according to project requirements and expected usage.

IV. IMPLICATIONS FOR INDUSTRY

It is impossible to go through a major process like migrating to a new PDM system and PLM toolset without acquiring a set of "lessons learned". Each participating company had a wealth of these lessons, which are summarized in this section. The conclusions that come from a study like this can be numerous and wide-ranging. However, it is important that they be kept in perspective, which is to say they should not be generalized too far past the companies that participated in this study. When generalizing these conclusions, it is important to make sure that the company of interest is similar to the companies that participated in this study. Not all companies are large or have multiple divisions or have hundreds or thousands of people that may eventually use the new PLM toolsets.

In general, the selection, implementation, and configuration of PDM systems, as well as the migration of data between PDM systems, requires the development of a good process, the necessity for a champion at the upper levels of management, the need to organize and prepare your data *before* the migration starts, and the necessity to change corporate culture and the mindset of the users to accommodate the use of these new tools. When it comes to the actual migration process itself, the biggest point to be made is not to try everything at once. Form a set of "early adopters" who can help with the rollout, who can test various functions before recommending them to all users, and who can act as mentors within the different engineering groups once the toolset is released to everyone. In addition, it is important to communicate results of the migration to everyone involved, especially upper management. Finally, dedicated and consistent internal funding is critical to the success of this type of endeavor.

Having framed these conclusions in that sense, the following points are what the authors have gleaned as important conclusions based on the analysis of the interview transcripts from the participating companies:

- PLM toolset implementations typically began with the installation of solid modeling-based CAD systems. From there, the migration was to PDM tools and on to enterprise-wide PLM environments. This move occurred over a period of years if not decades. This time frame was most significantly impacted by software and hardware maturity and the level of planning done by the personnel involved. This process takes consistent funding and resources.
- The PLM toolset implementation must coincide with business processes. If not, it will be seen as inconsistent with corporate plans and will likely not be supported – by rank and file employees or by management.
- Communication is critical regarding the successes and failures of the implementation, and existence of a champion of these new tools is critical, especially at the management level.
- Develop corporate standards (if they do not exist already) for the creation and input of data into the PDM and PLM systems. This will make future migrations and upgrades happen more quickly and consistently.
- The adoption of these new toolsets typically occurred during one of two times: a new product release or a major revision to an existing project. It is often necessary for these scenarios to leverage the new and improved functionality of the toolsets to accomplish the goals of the new project. Morale is often high and the project is visible at the corporate level.
- The new PLM toolsets are often implemented in two ways according to organizational structure – either by product group or by

workgroup. If it was by product group, there were occasional issues about people moving from project to project with regard to security issues, but these were eventually overcome.

- The archival process of new design information as it moves through the PDM tool often follows the typical engineering releasing process. In order to accommodate this massive amount of data, sufficient resources need to be devoted to storage and hardware capabilities.
- All of the companies that participated in this survey currently use one of the following vendors and their tools for their primary PLM toolset functionality: UGS, Dassault Systemes, or PTC. While software maturity is always an issue, it is highly recommended that customization of these tools is kept to a minimum because new software releases can require future customization and customization is very expensive. If customization is chosen, it should be done in concert with the vendor.
- The actual migration of data from one system to another (whether it is with the same vendors tools or not) should be methodical and well planned. Consensus should be reached between all constituent groups, independent of the IT staff, as these individuals know their work processes best.
- A systematic testing process must be developed to verify the migration (or import) of data into the new PLM toolset. Do not simply take the claims of the vendor at face value. The vendor must be able to verify data compatibility from one version to the next.
- When moving data from one system to another, it should never be done all at once. Small (relatively speaking) groups of files should be prepared, imported, and results examined before attempting a larger migration of data. The process of importing entire data base instances should be avoided unless absolutely necessary. Most companies typically did it on a folder-by-folder basis. Most of the participants to date have moved a significant percentage of their new product or major revision files to the new PDM toolset, which generally accounts for terabytes of data.
- Do not short-change the training of personnel who will use these tools. It is critical that they have job-specific training in a timely fashion. Avoid falling into the trap of training everyone – this is typically unnecessary. Bring people up to a basic level of proficiency in most areas of the new toolsets, but after that point, training should be specific to their job. The difficult part is determining the “basic level” of proficiency, because this often varies by corporate processes and by the type of product being designed. To accomplish this, the companies typically spent hundreds of thousands or millions of dollars.

V. IMPLICATIONS FOR EDUCATION

The one of the most significant implications for educators related to the use of PDM tools in the classroom is exposure. It is very likely that students leaving a university setting for an engineering or technology position at a design- or manufacturing-related company will have to use some form of a PDM tool to manage their design data on the job. In the past, students could be instructed to use the file management functions within the computer operating system, but that does not provide a sense of security or stability when it comes to editing files associated with a design. It is critical for students to understand contemporary data management issues associated with the design of a product and the corporate personnel structure into which that fits.

A second implication for educators is one of technological literacy. PDM tools have become nearly commonplace within engineering design environments. Even at small-to-medium sized businesses, who may not have the available funding of a global corporation, software vendors have supplied mid-range solutions to at least handle the management of CAD data, if not additional file types. While the cost of PDM technology is not as low as CAD tools have becomes in terms of educational discounts, it can be had at a reasonable cost if it is made a priority.

A third implication for educators is the impending commodity status that the use of CAD tools has now achieved. Early in its development, CAD technology required specialized training and expensive workstations to operate it. With the advent of Windows workstations and powerful, relatively inexpensive graphics processors, CAD tools have become a staple in most engineering and technology programs. It is the use of PDM tools and other higher-order technologies that will enable students to develop new paradigms of thought about the design process. It will also require faculty to develop more creative instructional opportunities and to change their focus from a production mindset to one of technological integration. While the creation of geometry will always be important, a secondary focus of engineering design graphics education is now developing – a view towards leveraging the 3D database within the larger context of the design environment. To facilitate that process, literacy in the use of PDM tools as a communication and dissemination backbone will be required.

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Table 1

Interview Question Used with Participating companies

1. What year did your PLM implementation start?
2. How long did it take?
3. Which factors had the most influence on this time frame?
4. Which PLM tool set(s) has your company recently implemented? Specifically, which of the following have been implemented and which vendor was used:
    a. CAD tool(s)?
    b. CAM tool(s)?
    c. Data Manager and vault?
    d. Computer-aided Process Planning (CAPP) tool(s)?
    e. Analysis tool(s)?
    f. Enterprise Resource Planning (ERP) tool(s)?
5. What were your company's prior capabilities in the aforementioned toolsets, including vendor:
    g. CAD tool(s)?
    h. CAM tool(s)?
    i. Data Manager and vault?
    j. Computer-aided Process Planning (CAPP) tool(s)?
    k. Analysis tool(s)?
    l. Enterprise Resource Planning (ERP) tool(s)?
6. If there is a difference in vendors between Question 4 and Question 5, how did that come about? What were the issues that had to be dealt with? Have they been resolved? If not, what is delaying that resolution?
7. If there was no change in vendors (as implied in Question 6), was there a change in version of the aforementioned PLM tools? If so, what issues had to be resolved? Has that process been successful? What were the factors that made it successful, or that have kept it from being successful?
8. Have you continued to use your prior PLM tool sets? If so, why and in what capacity? Is there a plan to eventually stop using them altogether? Can you share the details of that plan?
9. What type of archiving strategy was employed during the implementation of your PLM tools and strategy? Which internal groups were represented in the planning process? How were workgroups determined for PDM configuration? What strategies were used for establishing permissions, security, and design control within the database?
10. How was the data archival process determined? What were the critical factors used in the decision making process?
11. Describe the overall data migration process from the prior set of PLM tools to the current (new) set of PLM tools:
    a. How was the process determined that controlled the migration of legacy into the new PLM tool set? What were the major steps of that migration process? How much data was moved?
    b. How was the process determined that controlled which files were converted to the new file type (if applicable)? What were the major steps of the conversion process? How much data was converted?
    c. How was the process determined that controlled the creation of new data within the new PLM tool set? How much new data was created and archived?
    d. What was the timing of the new PLM tool implementation? Was it strategic or did it happen at the first available time?
    e. What lessons has your company learned throughout this process? How have you taken advantage of those new insights? What would you do differently if you could do this PLM implementation over again?
12. How was the training strategy developed to train people in the use of the new PLM tool set?
    a. How many people were trained? Which workgroup(s) was (were) given priority?
    b. Is there a 1-to-1 ratio of PDM seats to CAD seats? If not, what is the ratio? What was the rationale behind this ratio?
    c. Was this training created and administered by in-house personnel or from the PLM tool vendor? How was this decision made?
    d. How was the training budget determined? What was the overall amount allotted? Did that prove to be enough? Too much? Too little?

Table 2

PLM Tools Recently Implemented by Participating Companies

	CAD	**CAM**	**PDM**	**CAPP**	**Analysis**	**ERP**
Company 1	Pro/E	Pro/NC; UG Mfg.	TeamCenter Engineering	Internal tool	NASTRAN; ABACUS; PATRAN	Internal tool
Company 2	CATIA V5	None	SmarTeam	None	CATIA FEA; ABACUS; ADAMS	SAP
Company 3	Pro/E	Pro/MFG and AutoCAD	Intralink	None	ANSYS; Pro/MECH.; CE/Tol	Oracle
Company 4	CATIA V5	CATIA Mfg. Tools	SmarTeam/ ENOVIA	Internal tool	Multiple tools	*Not sure*
Company 5	CATIA V5	CATIA Mfg. Tools	TeamCenter (workflow)/ SmarTeam (concept)	Internal tool	*None specified*	Mainframe MRP
Company 6	Pro/E	Pro/MFG; Pro/NC; DELMIA	Intralink/ Winchill/ MatrixOne	Internal tool/TC Visualization	ABACUS; ANSYS; EDS Jack	SAP
Company 7	UG	UG CAM Tools	I-Man	I-man	PATRAN	Mainframe MRP
Company 8	UG	UG CAM Tools	TeamCenter; internal tools	None	ADAMS; noise analysis tools	BOM PeopleSoft
Company 9	UG	TeamCenter Mfg.	TeamCenter	Various tools/TC	Custom code	MatrixOne
Company 10	CATIA V5	CATIA V5	ENOVIA VPM 1.5	SAP	CATIA; FEMAP; NASTRAN	SAP

Table 3

Original PLM Tools Which Participating Companies Replaced

	CAD	CAM	PDM	CAPP	Analysis	ERP
Company 1	Internal Tool – 2D	Internal system built on CAD system	Internal Tool	Internal Tool	Internal Tools	Internal tool
Company 2	UG; SolidWorks; AutoCAD	None	I-DEAS TDM	None	Internal Tools	Internal Tool
Company 3	BRAVO; AutoCAD; Microstation; CADDS 5	None	CMS	None	None	Copics
Company 4	CATIA V4; Pro/E; UG	CATIA V4 Mfg.; NC Mill	Internal tool	Internal legacy CAPP tool	NASTRAN; CATIA	None
Company 5	CADAM; CV	None	Metaphase; I-man	Internal Tool	None	None
Company 6	PTC Legacy tools	PTC Legacy tools	Pro/PDM	Internal Tool	*Nothing listed*	*Nothing listed*
Company 7	Internal wireframe modeler	CAD-E	Internal Tool	Manual planning system	Internal Tool	MRP
Company 8	Legacy UG tools	UG Legacy tools	Internal Tool	Internal Tool	Many Commercial Tools	MRP
Company 9	UG (standalone)	Internal tools	Metaphase	Various Internal Tools	Many Commercial Tools	IBM Mainframe system
Company 10	CADAM; CATIA V4	CATIA V4	Default file system	Multi-CAPP	CATIA V4; PATRAN; NASTRAN	PIOS