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Specification and Development of Intranet-based Product Data Management Tools for the Furniture Industry

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Many furniture companies, especially small to medium-sized ones, are in the process of exploring the move from two-dimensional CAD technologies to three-dimensional, constraint-based CAD tools interfaced with product data management (PDM) systems. For many companies, their current organizational structure is not well suited to fully leverage the capabilities of new CAD/PDM technology. Using an initial assessment done as part of last year's project with the FMMC, an in-depth analysis of the product information creation and management process was performed at one furniture company. This work was done in conjunction with an analysis of current trends in CAD/PDM tools, especially as they relate to Intranet technologies. The resulting synthesis led to the development of a number of demonstrations of how product information could be developed and managed in a furniture company. Of particular interest was the role user-centered, site-based techniques played in helping this company with its integration process.

INTRODUCTION

Many furniture companies, especially small to medium-sized ones, are in the process of exploring the move from two-dimensional computer-aided design (CAD) technologies to three-dimensional CAD tools interfaced with product data management (PDM) systems. For many companies, their current organizational structure is not well suited to fully leverage the capabilities of new CAD/PDM technology. Both professionals within these companies and outside consultants have been challenged by the task of integrating new CAD/PDM technologies.

The formal study of integrating technologies into organizations is still quite young, resulting in a lack of appropriate tools for assisting with this integration process. Though Badham (1995) notes the lack of clearly defined methodologies for managing the change process, there are a number of general guidelines which have broad support in reported case studies. Badham points to the need to clearly understand the context of the individual company, its state, its needs, and goals. Salzman & Rosenthal (1994) warn that initially one should expect limiting and conflicting initial perspectives on the new technology. Development of scenarios to demonstrate the both the current and future state of product data development and management can be a key method for developing a common, effective vision for integration (McGraw & Harbison, 1997). Work by D'Souza & Greenstein (1996, 1997) demonstrates the use of this context-based, participatory approach in evolving the product development process in a manufacturing-based company. Matched with a clear grasp of the current state-of-the-art in CAD/PDM technologies, a user-driven, context-based approach can be the cornerstone to an effect change strategy.

It is important to note that in order for a change process strategy to be accepted by a medium-sized company grappling with rapidly changing technology, the technology integration process has to be quick, involve a minimum amount of human resources, and have a high degree of face validity (Karababas & Cather, 1994). The lack of clearly defined, well-validated tools for managing this process means that all methods used should be carefully documented and evaluated for its effectiveness in supporting the technology integration.

INITIAL COMPANY ASSESSMENTS

During 1997, work was done with four furniture companies who had expressed interest in integrating 3-D CAD/PDM systems into their product engineering operations (Wiebe, Norton, Summey & Howe, 1997). This first phase was largely ethnographic in nature, consisting of one or more site visits, surveys of individuals directly involved in the product development process, and structured interviews with key members. These surveys served a number of purposes, including: 1) Providing an overall company structure, 2) providing an initial outline of the product development process in these companies, 3) giving a better understanding of the current problems each of these companies were facing, and 4) beginning to provide an understanding of the future goals the companies had for their product data development and management process.

Though the specifics of problems faced by these four companies varied, there were some general trends. First, all of these companies saw themselves buried in paper. While the product design process had changed little in the last fifty years, in response to market demands, the companies all found themselves producing shorter runs of pieces from an ever-expanding product line. Though these companies had brought in 2-D CAD tools over the past ten years, none of them had significantly changed their development process. This finding parallels the findings of Adler (1989) in other manufacturing industries. All of these companies had a great desire to reduce the amount of costly and error-prone manual transfers of redundant data.

A number of important conclusions were reached as part of this initial survey. Most of them centered around the general realization that bringing new technologies into a manufacturing organization without also examining the organizational structure would not solve core elements of inefficiency (c.f., Cheng & Kirkwood, 1997). With many of the companies, the short term goal was to use technology to solve their perceived problems, even though many of the systemic organizational problems could be addressed without any changes in technology. However, many of the middle and front line managers leading the drive for new CAD/PDM technologies realized that the new technology integration would be an opportunistic time to address other organizational issues.

MAPPING CURRENT PRODUCT INFORMATION FLOW

One of the four companies initially surveyed indicated in the second quarter of 1997 that they were planning on implementing a new 3-D CAD/PDM system during the first half of 1998. During this time, the central engineering division of the company formed a pilot team consisting of representatives from the product engineering and manufacturing groups. The authors worked with the pilot team during the last half of 1997 to develop goals for the modeling system, benchmarks for evaluating the systems, and participated in the system reviews. A key component of the work being done with the pilot group was to look beyond the specifics of any one CAD/PDM system and identify the general technical capabilities of the desired system and begin to explore how this system could impact the organizational structure of the product development process. This exploration began the process of understanding how this technology could affect changes in information generation and flow, job design, and organizational structure.

During the period preceding the selection of a new 3-D CAD/PDM system, a second set of in-depth interviews with the pilot team were conducted to better understand the current product information flow. This process paralleled techniques used by Karababas & Cather (1994) and McGraw & Harbison (1997). Given that a main focus of the integration effort was to change the way product information was created and managed, archival documents were used extensively as part of the interview process. Documents such as drawings, sketches, notes, bills of materials, manufacturing instructions, etc. represent cognitive artifacts used in collaborative work (Olson & Olson, 1991). Though these documents were weak on capturing implicit knowledge, they served to develop a common context when used in conjunction with interviews.

Another important outcome of the second interview round was developing a better understanding of the goals of the pilot group and upper management. In the case of this company, they wanted to develop a higher degree of agility to respond to engineering and design changes. Currently, changes in design, especially those implemented as the product moved closer to final production, significantly heightened the risk of introducing dimensional errors into the parts. An equally important part of streamlining the product engineering process was being able to bring a design to production in a shorter period of time. A parallel goal was the development of uniform design and manufacturing standards. This long standing issue evolved out of the power relationships between central engineering and individual factories. With a new, networked CAD/PDM system, centralized control of engineering design work was seen as a desired outcome by the pilot group.

Based the first and second round of interviews and the archival documents, a first draft of product information flow charts were developed (see Appendix A). The product development process was divided into seven fundamental stages. These stages were:

- Design
- Assembly Detail
- Bill Out
- Shop Floor Control
- Plant
- Product Review

Most of these stages were passed through twice: once during initial design and sample construction, and again if the product went into production. The

Design stage happened only once at the very beginning of the sample phase, while the Product Review stage was situated between the sample and production phases.

Within each of these stages, the activities involved, the documents produced, managed, or modified, and the destinations of this information were mapped. This product development process involved one to three revisions of 24 separate documents types for each piece of furniture as it went from initial design concept to the first production run of the product. In most cases, there would be further revisions to many of these documents as additional problems were revealed in the production process or as the marketing division requested aesthetic or functional changes.

These documents, coupled with the interviews, revealed a number of important pieces of information. First, embedded in each document were certain types of information needed in the development process. The process flow charts revealed whether this information was being developed in a serial or parallel manner, who this information was being distributed to, and when the information was redundantly encoded and managed in multiple documents. Second, the 'business rules' of the information were revealed. That is, who was responsible for the generation, management, distribution, and approval of the information along with rules for who was allowed access to it. Finally, the interview and charting process helped reveal the 'engineering rules'; helping to understand the decision process involved with making sure the product represented a cost effective, structurally sound, and aesthetically pleasing piece of furniture.

After the initial version of the flow charts were developed, they were sent back to the company. Shortly thereafter, a meeting was scheduled and information exchanged concerning clarifications and corrections to the charts. The charts were then revised based on these comments. This process was repeated two more times for a total of three rounds of revisions. The final flow charts plus a master document list are included in Appendix A.

As a result, this process both helped to build an understanding of the product work flow for the investigators and within the pilot team. Though the pilot team members each had at least ten years experience at the company, they each admitted that they learned more about other peoples' job responsibilities and how particular types of information was generated and revised by going through this process. Pilot team members noted that this was the first time that they had seen the full work flow process detailed to this degree; a process that they were all intimately involved with on a day to day basis.

DEVELOPING FUTURE-BASED SCENARIOS

The development of a robust model of the current state of the product information development and management process served the dual purpose of both clearly defining the current state, and opening discussions of how this process could or should change in light of the proposed integration of new CAD/PDM technologies. Developing 'future-based scenarios' (D'Souza & Greenstein, 1997; McGraw & Harbison, 1997; Neale & Kies, 1996; Ziegler & Barnekow, 1997) was not only used early in the process to help define the proposed uses for the CAD/PDM software, but also to help plan the implementation of the system and the changes which where likely to occur in the product development process.

Assessing Basic CAD/PDM Functions

In order to develop future-based scenarios of the product development process, there has to be an understanding of the basic functions which a CAD/PDM system would fulfill. First and foremost, a contemporary 3-D, constraint-based CAD system is a geometry engine used to create virtual models of proposed or existing furniture pieces. Embedded in the model are either implicit or explicit relations between features on a single part or multiple parts. Implicit relations built into a part might be that two faces are parallel or that a corner is 90 degrees. An explicit relation might be that a tenon and mortise to be joined share common dimensions. Other information contained in the model might be a hierarchical structure for the parts defining a series of sub-assemblies and parts and how they relate to each other. Other text or numeric information can also be embedded in the part, such as part number, model creator, date modified, etc.

The PDM component plays a complementary role by both managing information created within the CAD system and integrating with it additional product information created by other means (LaCourse, 1996). This basic functionality can be described as serving one or more of the following purposes:

- Document vaulting
- Workflow management
- Revision control
- Parts databases

Document vaulting provides a secure, digital container for information related to the product development process. As alluded to earlier, this can include both files created within the CAD package or elsewhere. Other information might include scanned sketches, spreadsheets, images of fabric swatches, etc. The vault provides access control for the information contained within. In theory, it means wider access to product data since a finer degree of control can be exercised over the information. For example, a majority of people in the product development process can have on-line, view-only access to the information while a much smaller number can actually edit the document. A document vault also provides a central location for data where it can be easily maintained and archived.

Workflow management assists in the management of the evolution of the product information database throughout the development cycle. This includes management of the movement information to and from local computers throughout the organization and the dating of changes made by users. Often used in conjunction with these functions are communication systems such as e-mail for providing a notification system for those needing notice of changes or to-do actions. An important component of the workflow management process is revision control. Enterprise-wide distribution of electronic documents must be accompanied by fail-safe controls on who may edit information in the database and who may approve these changes. These changes and approvals are linked to revision level information attached to the file in the database. For example, numerous engineers may have access to a particular CAD model at any point in time, but they would be able to immediately tell what changes had been recently made to the model and by whom. Just as importantly, they would be able tell which of these changes had been approved by their superiors. Ideally, information on what other components are affected by these changes and who is responsible for the updating them would also be available.

Parts databases are a natural offshoot of a CAD/PDM system. Often, the creation of individual parts in a 3-D modeler take just as long as it would to create them via manual drafting or 2-D CAD. If the part has been fully constrained internally, constrained within an assembly, and/or had its constraints logically labeled, the modeling method will likely take longer. Time spent performing these tasks will only be cost-effective if the part is re-used numerous times in other assemblies. The time taken to carefully implement and notate the constraints will, in turn, make it easier to modify the part for use in other assemblies. The PDM system plays the role of managing the database of re-usable parts, making it more efficient for the designer to retrieve and re-use parts rather than model new ones from scratch.

Emergence of Intranet-based PDM Tools

One of the technological trends which has accelerated the adoption of PDM tools has been the emergence of Intranets: internal corporate networks based on open Internet standards. Intranet technologies have substantially brought down the cost of PDM systems by allowing what have become ‘ubiquitous’ system elements to be used in place of expensive, proprietary PDM system elements (Miller, 1998). For example, free Web browsers can now be used in place of expensive client software. On the server end, there is movement towards the support of mainstream databases such as Oracle or Sybase and the linking of these databases to the Web server and/or Web browser. In a three-tiered system, the Web server would pass calls from the Web browser for information to the database, then configure the data in a Web-readable form for the browser. Server-side Java, CGI, or other programming tools would be used for building these pages and providing the interface with the database. With a two-tiered model, the Web browser still receives standard HTML pages from the Web server, but requests for database information are passed directly to the database. This interface is managed with client-side Java code downloaded to the browser. The use of industry-standard databases coupled with increasing availability of database interoprability tools means that previously isolated databases containing financials or manufacturing information can be linked to PDM systems and served through a common Web browser.

Information served to Web browsers from database and Web servers can take a number of forms. On possibility, if CAD data is involved, would be files in the native binary format of the CAD software can be downloaded and then viewed within the native CAD system. This approach has a number of disadvantages. First, the native binary format files tend to be large (with exchange formats such as DXF and IGES being even larger), leading to long download times. Second, the client machine downloading the file would have to have a copy of the CAD software, defeating the cost-effectiveness of the free Web browser. Finally, the user would have all of the overhead (e.g., cost, load time, computer requirements, and training requirements) of the CAD system when in many cases, all they needed was view-only capabilities. Increasingly, CAD and PDM vendors have provided one or more alternatives to this approach. A common approach is for the CAD vendor to provide translation to a neutral format that is either MIME-compliant and/or supported by a wide variety of third-party plug-ins, ActiveX components, or Java tools. An examples of these are: CGM and VGML (open, MIME-compliant standards) and DWF, developed by Autodesk. The advantages of this approach is that it provides a common file format tuned for delivery over the Web and more readily supported by browser plug-ins. The disadvantages include the need to perform an initial translation of the CAD files along with the possible loss of data. A compromise approach is to provide a specialized viewing tool for the browser which supports the native file format of the CAD system. If the CAD system uses one of the third party modeling kernels (e.g., Parasolids or ACIS), then a browser viewer provided by the kernel developers can be used.

The end result of browser-compatible viewing tools is the ability for numerous people in the company to be able to access CAD data served from databases with free or inexpensive viewing tools. These viewing tools differ from standard in-line graphics in that they are truly vector-based, allowing for real-time panning, zooming, and rotating without loss of resolution. The more sophisticated of these viewing tools also allow red-lining and notation along with access to the matching CAD binary file.

Integration of database tools with communication systems

Equal in importance to the development of Intranet-based tools for direct management of product information is Intranet-based support for the group-based, interactive process of evolving product data (Wiebe, 1997). While Intranet-based PDM systems allow for product information to be dispersed throughout an enterprise, other communication tools need to be integrated with the system to fully utilize its capabilities. When product data was paper-based, face-to-face meetings of the stakeholders around a conference table was often the optimal approach to work through design and engineering issues. With the same product information existing in electronic form, and accessible from any computer, face-to-face meetings need to be reserved for when it is feasible to bring together geographically disperse project teams and the negotiations are complex enough to warrant the richness these meetings offer (Lakin, 1990; McGrath & Hollingshead, 1993).

Alternatives to face-to-face meetings include electronic mail (e-mail). Though most companies have implemented some form of e-mail, many systems are not used as effectively as they could. Tight integration of e-mail with the types of activities which PDM is also supporting means having e-mail as an alternative channel for carrying much of the same types of information that is served though a Web-browser. The same MIME-standards which support the viewing and distribution of PDM-based files through a Web-browser can also be used to support e-mail attachments between project participants. Scanned sketches, notations, spreadsheets, and CAD files which are not ready to be posted in the PDM system can be shared either formally or informally via e-mail attachments. E-mail also provides a quick and easy way to attach written comments to a document. Even without attached documents, e-mail is a powerful notification system for alerting others to changes or action items for information in the PDM database. How and when such sharing and notification happens through this alternative channel is decided through a combination of situation, agreements within the workgroup, and company policy.

Whereas e-mail provides text-based, asynchronous communication, there are times that synchronous communication is desired. Whiteboard software allows real-time markup of documents and freehand sketching over the company network. Often accompanied by audio transmission via computer or phone, such 'on-line' meetings can capture many of the interactive elements of a traditional meeting without needing to physically be in the same place. Whiteboarding activities or general discussion of project goals can also be enhanced with video-conferencing technologies. While still not capturing the full social richness of a face-to-face meeting, video transmission adds another dimension to communication when needed.

With such a wide array of communication medium and types of paper and electronic information, careful consideration needs to be made as to what combination of product data, supplemented with what type of communications technology communicated, to which individuals, is appropriate for a given situation. Some of these decisions can be formalized in policy (e.g., all final design reviews will be face-to-face meetings with certain managers supplied with specific documents) while others are ad-hoc decisions made over the course of a work day. There is no question, however, that team members well-versed in the available technology and managers monitoring communication patterns for overall effectiveness can greatly optimize the use of these new avenues for information exchange.

Scenario Development

In parallel with the development of the product workflow charts, specifications were being developed concerning the new CAD/PDM system. Knowledge of the current state-of-the-art of CAD and PDM systems, coupled with current trends in Intranets, was conveyed to the pilot group during discussions. In addition, these technologies were also used to create demonstration scenarios of how product information could be created and managed.

Once the CAD/PDM system had been narrowed down to a particular class of system, a representative CAD software package was used to create a ‘generic’ furniture piece based on the archival documents used in the workflow analysis (see Appendix B). In addition, the same archival documents were scanned and converted to Adobe Acrobat (.pdf) format (see Appendix C). Once in pdf form, optical character recognition (OCR), redlining, and notating capabilities within Acrobat were used to demonstrate how legacy documents could be converted to electronic form and enhanced to provide key pieces of product information in digital form. Whereas the workflow charts showed how product information was currently developed and handled within the organization, the demonstration model helped show how the same information could be restructured into new electronic forms and what new types of information could be generated.

The CAD software demonstration showed to the pilot group how many of the engineering rules, currently tacit knowledge held by designers and engineers in the group, could be transformed into explicit knowledge contained in the CAD model. This transformation would, however, involve a fundamental shift in how product information was managed in the group. In addition, there was considerable time involved with embedding ‘design intent’ into the CAD models. This time spent would only be transformed into an advantage for the group under certain conditions, including: 1) that manufacturing processes were standardized to a degree that the manufacturing-driven design features used in one model could be re-used in other models, 2) that the functional and aesthetic design of the piece represented a generic class of furniture which would be represented in many other pieces, and 3) that the designers and engineers have enough control over the product development process to enforce certain conventions in model construction and modification.

The final draft of the workflow charts, coupled with the CAD models, were used for a capstone meeting representing the move from ‘here we are now’ to ‘where we want be’. Though future goals and CAD/PDM technology capability had been discussed from the very beginning of the project, the project had matured to the point where there was now a very tangible common basis for understanding moving forward into a pilot implementation of the recently purchased system.

Planning Final Implementation

The next phase of implementation for the company was the actual purchase of a CAD/PDM system and the initial training of pilot group members. This phase of implementation involves team members merging higher level product data generation and management strategies with the specifics of the system purchased. With a smaller pilot group, such as this company had, it will be easier to simulate the initial generation of parts and assemblies than it will be the overall product information workflow. Some of the workflow can be simulated as it was in the earlier scenarios and at a higher fidelity with the actual system to be used. At the same time, until all of the company units which are going to use the product data are involved, all of the technological and organizational issues will not be faced. Still, the time invested up front will help prepare the pilot group for possible trouble spots and strategies for helping smooth the implementation. Also, this company is not atypical in that the short term PDM implementation will be used largely in Product Engineering, with a wider implementation awaiting the purchase and integration of a larger, enterprise-wide data management system.

The final phases of implementation will be strongly influenced by the amount and type of early planning done by the company. Still, the quality of the initial planning stages can be undone by poor follow-through after the system purchase is complete. Common problems include: Inappropriate training for the initial pilot group, inappropriate group size, and staging implementation beyond the pilot group. The pilot group can receive both too much, too little, or poorly timed training. Ideally, the training is provided on a 'just-in-time' basis. Constraint-based 3D modeling systems and their associated PDM components are very large and complex tools. It is likely that only a portion of the all of the available features are going to be used in the initial implementation phase and some of the tools are likely to never be used, even after full implementation. It is important not to overwhelm group members with unnecessary features when focus on the problem at hand is so critical. Both too large and too small a pilot group can be a problem during the early phases of implementation. Too large a group will run up the costs of off-site training and create communication and cohesion problems during the formative implementation period. Too small a group can put too much pressure on those in the group and creates a high-risk situation. What could be worse for a project than have all of the critical knowledge contained in one person, only to have that person leave because of burnout or disagreements over the direction of the project? Even a successful prototyping by the pilot group doesn't assure success. The system then has to move beyond the pilot group to the rest of the organization. Just as difficult as the prototyping will be the 'selling' of the system to expanded group of potential users and providing training and guidance for its implementation.

SUMMARY

In summary, whereas the initial phase of the project helped define a general domain understanding of the problems facing a small group of companies, the second phase of the project helped define a course of action for an individual company. This companies' course of action for the integration of a CAD/PDM system was informed in part by the methodology described in this paper. A common understanding of both the current product development and management process and how the new system might affect it was forged through site-based work involving extensive user input and archival documentation. Current trends in CAD/PDM systems and Intranet technology were used to help understand alternate modes for the generation, storage, transport, review, and editing of product information. From the information gathered, scenarios were generated both of current and future states to help guide the decision-making.

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APPENDIX A.

Product Information Flow Charts

1. Flow Charts. The charts, in the basic order in which they pass through product development process, track the documents which contain the current product information. These charts represent the third (and final) revision based on feedback from the pilot team. Each sheet delineates the current responsibilities of organizational units in terms of what documents they create, modify, or review, and which units they pass this information on to. Documents for which the research team had a copy of are represented as thumbnails. The alphanumeric code on the documents are referenced in the Master Document List.

2. Master Document List. This list represents all known formal documents used in the product development process. The alphanumeric code is used for referencing the documents on the Flow Charts.

APPENDIX B.

Sample CAD-based Documents/Data

1. 2-D Parts Drawings. These drawings were generated from 3-D, constraint-based part models of the furniture parts. Individual companies, based on their revised product development model, may or may not continue to use traditional parts drawings such as this one.

2. Exploded Assembly. Exploded full assemblies, such as this one, or smaller subassemblies can be generated very quickly from 3-D, constraint-based assembly models of the furniture pieces. These exploded views may be used both in product engineering or in manufacturing to assist with assembly.

3. Assembled Detail Drawing. Unlike in traditional product development processes, this assembly drawing comes after individual parts are modeled. Though individual part modeling may be informed by initial assembly sketch models, the final detail model usually comes at the end of a modeling cycle. Once built, however, changes affecting the multiple parts in the assembly can usually be easily accomplished in a fully constrained assembly.

4. Bill of Materials. This BOM was generated with a minimum of manual input from the 3-D assembly model. This BOM will also automatically be updated when data in its fields (e.g., finished overall dimensions) is changed in the assembly model. This BOM is example of how time savings can be achieved and manual errors reduced when the time is taken to build and fully constrain virtual models of the furniture pieces. The time spent building the model can only be leveraged when the model represents a design which can be iterated into future designs and model building and design standards are in place which encourage its re-use.

APPENDIX C.

Sample PDF Documents

1. Initial Scan Conversion. Legacy documents like this parts sketch and route sheet can be scanned using an inexpensive 300-600 dpi scanner. Large scale scanning will involve the investment in an industrial grade scanner with an automatic document feeder. At this stage, these documents contain only bitmap (raster) information suitable for printing on standard inkjet or laser printers and storage and distribution via electronic networks. These documents were stored in TIFF format, a standard bitmap format. This format is read by most all major packages working with bitmap images, but cannot be viewed on Web browsers without conversion or a plug-in.

2. OCR and Cleanup of Key Fields. Adobe Acrobat was used to convert the TIFF files to Acrobat (PDF) format. Part of this process is to perform optical character recognition (OCR) on the document and convert all recognizable text to machine-readable ASCII text. This allows the converted text to be searched and indexed by databases. If necessary, the user can ‘clean up’ the document by manually converting bitmap characters to ASCII text. This might be done for key fields, such as the part number or suite number, when OCR has failed. In the sample part sketch, only the typed text in the upper left hand corner was successfully converted. In the route sheet, about two-thirds of the text was converted. The converted text has finer, cleaner lines. Security capabilities of Acrobat allows the document to be locked as read and/or print only. PDF documents can readily be viewed and/or printed from Web browsers using a free plug-in.

3. Redlining Examples. Additional plug-ins (e.g., Re:Mark) can be purchased which allow a redlining layer to be placed over the Acrobat document. In this part sketch example, the overall dimension was increased by two inches and the bore offsets from the two ends increased by an inch each. These redlines are kept separate from the original document and can be notated with names, dates, and other pertinent information. Documents can be viewed and/or printed with or without this redlining layer.