Creating a Flexible Data Management Environment in CAD/CAE/CAM for Product Lifecycle Management

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Abstract

Most commercial CAD/CAE/CAM software programs offer Product Data Management and Product Lifecycle Management functionality that incorporates 3D design/graphics, engineering drawings, digital archiving and revision control, collaboration tools and centralized databases for managing information and facilitating reduced times to market. Although these systems are powerful and available for product designers, engineers and managers, over-stated capability and cumbersome user interfaces often fail to deliver on promises made to customers. In addition, the resources for implementing these programs and the high cost of software licenses have forced many companies (especially small-medium sized) to post-pone or reconsider plans to invest in this promising technology. This paper describes a methodology for streamlining the engineering and development of new products using computer aided applications and software made using Application Programming Interface tools. Advances in computing and engineering will bring new ideas and innovation to make the product development process more agile and customizable to the needs of each company. This paper focuses on combining the areas of CA'X' based product development and software engineering to address some of the shortcomings of "off the shelf" programs and raise awareness of the possibilities that exist when CAD/CAE/CAM is viewed as the hub of a more integrated and flexible working environment that is rich with accessible information.

1. Introduction

Making good investment choices in CAD/CAE/CAM software is very important as modern product engineering and manufacturing and data management occur in an almost completely Computer Assisted environment (CAX). It has been said that the companies that will thrive in the post-recession decades will be those that have learned to manage and share data both internally and with customers/suppliers using the tools and concepts of Product Data Management (PDM) and Product Lifecycle Management (PLM). Many stand-alone software programs are sold as having fully integrated functionality and partnerships between software vendors are common, often reaching the "Gold Partner" status (an example of this is Solidworks with MasterCAM). This means that the two programs are operated from the same user interface but they continue to operate out of separate databases and lack consistency with terminology, philosophy and operation. The positive result of these efforts is that designs can be passed seamlessly from design to analysis to NC programming with a single model that will automatically update based on changes at any stage. They provide interoperability and associativity to connect processes together creating a digital product definition. Software developers are using Application User Interface (API) tools to link the programs and the transfer of data has become much better. Although there have been great advances with this technology over the last decade, there is still a lot to be done before we can openly interrogate model databases and then extract, organize and make information available across not only product engineering and manufacturing but, in the business cycle and in customer/supplier relationship management as well.

In the not so far off future, systems and applications including CAD/CAE/CAM, Enterprise Resource Planning (ERP) systems, Customer Relationship Management (CRM), Supply Chain Management (SCM), Product Data Management (PDM) and Product Lifecycle Management (PLM) will be seamless and customizable. Currently in industry, company philosophies, work standards, levels of process integration, use of technology, sharing of digital

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information, types of products and the desire to use advanced software varies greatly across the board as companies try to provide product customization and faster times to market. Although CAD/CAE/CAM vendors sell the idea that systems are completely adaptable under all the above mentioned conditions, this is currently not true. Customers who buy into this sales pitch are often disappointed after spending many thousands or tens of thousands of dollars and not achieving the desired results or return on their investment. There are many reasons for the lack of success, including a steep learning curve, a very slow implementation cycle, bad planning, a lack of and understanding of the current system, general confusion about the concepts, far too much functionality for what is needed and resistance from engineers and key personnel that are not willing or able to change. Industry and education need to work together to design flexible data management tools that streamline product development and engineering using CAD/CAE/CAM and custom software applications. Engineers with software skills and business experience will be a big asset to industry. Currently, PLM/ERP/PDM software that is available falls short at providing the capability to personalize software based on company, product and industry practices and specific processes. As international standards are developed and implemented on a widespread basis, the need for companies to confront compatibility issues will also continue to grow.

2. Background and Related Work

There has been extensive work done to streamline product development using CAD/CAE/CAM and business process integration. There are both commercial examples available as well as research as discussed in the literature. A very interesting point about the work studied while preparing this paper is that there is as much if not more interest internationally in PDM and PLM than in the USA, this is especially true in Europe. One reason for this is that product development is now going on 24/7/365, and often takes place at multiple points across the globe, in countries speaking different languages and utilizing diverse programs and methods to complete the job. As this trend continues to grow with globalization, web/cloud based applications and CAX technologies, the need for standardization and data compatibility will only continue to grow. A typical scenario that exemplifies this idea is that a aerospace product is specified and needed in Italy, the engineering design is done in Spain, the final assembly is in Germany and the software used for the job is developed by a company in France or England. In order for design intent and improvement, prototyping, tooling, production and quality control to work together under these circumstances, there must be a high level of confidence in the data that is being exchanged. A few of the related works that were found are reviewed below.

2.1. Integrated and Standardized CAD/CAM Research

For data management from a manufacturing perspective, some researchers are looking at the STEP-based standards as a solution. Xu and He, in a 2004 paper on striving for total integration of CAD, CAPP, CAM and CNC, present STEP NC as a generalized solution for the exchange of numerical control programs and the fact that old ISO standards have served as a barrier to CAD/CAM integration initiatives. The authors go on to recommend STEP-NC as a tool that has been harmonized with the overall STEP standard and the benefits that this standardization could mean for the management of product data that is produced using commercial software systems. The author says that restrictive tools from the past must be removed and new ones developed to create a more open, flexible and efficient environment [1].

In a recent article from www.designworldonline.com, author Evan Yares speaks to the dilemma of choosing an integrated CAD/CAM system. He identifies the integrated CAD/CAM functions in Siemens NX using stage models, based on a common master model. These are 3D representations of the part at each stage of the machining process, and can be used for inspection, documentation, fixturing design, and more. In the same article, Jeanne Naysmith, from Cimdata points out that the first consideration, when looking at CAM software, should be the goals of the business owner. Who will be in charge of selecting the program, engineers, programmers or management? Companies should use a separate initiative to evaluate CAD/CAM while leaving the existing tools and processes in operation [2].

In a project using open standards based approach to exchanging CAD/CAM data in the electronics industry, the author utilizes Extensible Markup Language (XML) to provide accurate and up to date information that allows for more closely monitoring conditions and respond to problems and reassignment of resources. The paper goes on to describe how 9 companies have combined their efforts to produce custom API programs that can be embedded into various equipment manufacturer’s software and controllers with the goal being to reduce downtime, improve efficiency and eliminate manual data collection and management. The system includes a Message Broker so that other applications can subscribe to this information for real-time data analysis, identification of bottlenecks and producing history studies into root-cause, efficiencies and comparison of performance across shifts and other facilities [3].

2.2. PRODUCT DATA MANAGEMENT AND PRODUCT LIFECYCLE MANAGEMENT CENTERED RESEARCH

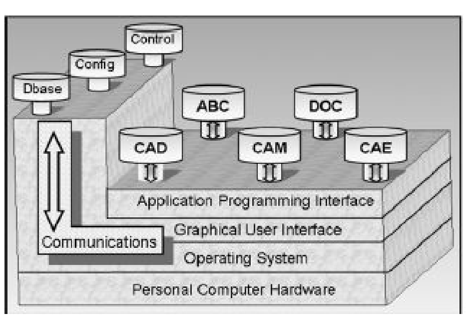
Some of the challenges in product development are globalized markets, specialized customer demands, more regulations on safety, sustainability, part complexity and quality expectations. Industry is increasingly reliant on using information technology to cope with these challenges. Systems for computer-aided design and manufacturing (CAD/CAM), finite element analysis (FEA) or analysis are widespread today but remain relatively stand-alone platforms. Incompatible data formats required by the different tools have been recognized as a major issue for product development in most industrial areas. As a consequence, the transfer of product models is often done manually using paper-based documents (drawings, reports). This creates a higher occurrence of rework and mistakes. Aerospace companies must meet customers' needs for world class products while remaining competitive and profitable. "There is pressure to deliver high complexity, technologically enabled products to fulfill customer requirements. One of the biggest challenges mentioned is to use compatible data coming from diverse systems to manage new product development. This paper presents a multiple case study approach of turbine blade manufacturing part families with a high tech aerospace company for application within a PLM environment. This method is currently being explored within the company so as to accelerate the design-make process to enable earlier availability of, and easier access to, manufacturing knowledge, thus bringing about better product performance [4]."

In their 2010 paper, Kang and Peng, [5] describe their system which provides data integration from design to assembly in a collaborative environment. They state that a key issue in Virtual Manufacturing systems is the integration of design information into different product development stages. A product design model has to be accessible and reusable by downstream applications, such as product process planning and assembly planning. However, existing product modeling systems cannot fully support the downstream applications. This paper presents a method of extracting product design information from its CAD models for assembly planning and tool accessibility analysis. A web-based interface is developed for the system implementation and the process simulation.

2.3. CAD/CAM INTEGRATION USING API

Another class of applications have emerged that use the APIs from commercial software applications to make product development more customized, automated and efficient and often are used to connect the CAX programs to programs used for business/cost analysis, customer and supplier relations or enterprise resource planning. Many efforts are underway to create web based and cloud based collaborative environments where data accessed through APIs becomes available to multiple site users for using and discussions. Angel and Shah [5], 2002 discuss the issues of integrating the Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) programs in commercial software. They implemented a Computer-Aided Process Planning (CAPP) system in the software using the API. The part model was imported into, or designed in the commercial CAD system. Manufacturing information was then extracted from the part model by the CAPP system using commercial Application Programming Interfacing API methods. The CAPP system then used the information to produce a process plan consistent with the CAM module to produce NC code. The integration was done with API methods that dynamically bind the CAD, CAPP, and CAM into a single continuous application. The system used Orbix middleware following the CORBA standard [6].

An earlier work from 2006 appeared in the RCIM Journal article titled "A Framework for Extending Computer Aided Process Planning to Include Business Activities and Computer Aided Design and Manufacturing (CAD/CAM) Data Retrieval"[7,8]. The system described in that paper was focused on developing an Activity Based Costing model so that order management, CAD/CAM product engineering and cost analysis were connected using API programs in Autodesk Inventor® and EdgeCAM®. The system was developed for a medium sized job shop with CAD/CAM and CNC capabilities. Figure 4 represents the program architecture as it was developed in 2006 for the journal paper.



GUI –	Visual Basic 6™
OS –	Windows XP™
CAD –	AD Inventor 6™
CAM –	PT EdgeCam™
CAE –	**Not Implemented**
ABC –	Excel Application
DOC –	Excel Form Set
Dbase -	MS Access™
Config. –	Visual Basic 6™
Control –	MS Outlook™

Figure 1. Framework of CAPP system with Activity Based Costing.

In the aerospace industry, the need for collaboration tools and data access in product development is especially important. One approach was the development of four scenarios to design a pull mode industrial solution that enables tier-one suppliers to securely and efficiently retrieve data for manufacturing purposes from original equipment manufacturers (OEMs). The research aims to facilitate and enhance product information sharing. The scenarios were developed using PDMLink®, a PLM and Microsoft SharePoint collaboration platform. "This methodology was implemented to select the most suitable scenario for utilizing the tools available in the PLM system to accomplish the pull mode data collaboration solution. The data for this research was collected in a number of ways including semi-structured interviews, workshops with experts and reviews of technical documentation on current processes [9]."

3. Description of the Current System

The approach described in this paper is to develop software tools that can be customized to the needs of a company using a Visual Studio programming environment for the main interface that serves as the system hub and connects the modules used for order entry, databases, design, engineering, manufacturing planning, scheduling, and shop-floor control through the use of custom API programs. Although the specific programs used for the system include MS Visual Studio®, Solidworks®, DelCAM® and MS Office®, other programs such as Autodesk Inventor®, MasterCAM®, Siemens NX® or Creo® from PTC offer API functionality and could be substituted to accomplish the same goal This is one of the benefits to this approach. The objective is to show how flexible and customizable applications can be developed using API's and custom utilities to address some of these problems and allow growth and enhancements to be added in the future as product development integration and process streamlining are better understood. The programs utilized to implement the prototype system included the following programs:

- MS Visual Studio 2014® using VBNet
- Solidworks® 2013 and API
- FeatureCAM® 2012 and API
- MS Office 2010 (Excel, Word, Outlook) and API

The basis of the proposed methodology is in understanding the difference between how CAD and CAM applications are operated normally and what capabilities are available through the software API. The brief description of what the Solidworks and FeatureCAM API offer will help with reading the rest of the paper.

SolidWorks API: The API contains hundreds of functions that you can call from Visual Basic for Applications (VBA), VB.NET, Visual C#, Visual C++ 6.0 , and Visual C++/CLI. These functions provide direct access to SolidWorks functionality such as creating a line, inserting an existing part into a part document, or verifying the parameters of a surface. SolidWorks Enterprise PDM is a project-data management application designed to run both natively inside of the SolidWorks environment and as a standalone application. The SolidWorks Enterprise PDM Application Programming Interface (API) is an OLE programming interface to SolidWorks Enterprise PDM, which allows you to automate and customize SolidWorks Enterprise PDM. For example, the SolidWorks Costing tool helps to:

- Calculate how much it costs to manufacture sheet metal and machined parts and create quotes.
- Make decisions based on the cost to manufacture.
- Create quotes for customers. Whenever a design is changed, the new updated cost can be seen immediately, along with a detailed cost breakdown. Automatic cost reports can also be generated.

FeatureCAM API: The API gives users the ability to make their own programming enhancements to FeatureCAM. They can customize FeatureCAM products to meet their specific requirements and preferences. Some of the things that can be done through the API include creating a custom Bill of Materials, extracting data including machining times from the current part database. A GUI could also be made to retrieve cutting data from an external file made in excel or a text editor. The program can be pre-configured based on company practices and preferences and streamlined creation of tool paths would be possible with the API functionality provided in FeatureCAM. These tools are very useful to shorten the planning and programming time, especially if standard company practices are adopted.

3.1. How the Program Works

Once the main program is run, the following GUI is displayed (Figure 1) and the user can begin to use the system. The tabs across the top of the screen represent the sequence of activities used by ABC AEROSPACE to process orders for components. The modules are Customer Service, Projects, Tool Design, Process Planning, Catalog, Production, Matrix (for scheduling), Collaboration and Summary & Data. Some main ribbon tabs have a second layer of sub-modules that are steps within the main process, Process Planning for example (Figure 2). The steps for process planning include CAD Review, Process Plan, Fixtures/Setups, NC Programming and Output Data. The idea is for the reader to see that the software was designed to follow the normal process used in the company.

Figure 3 shows the Design tab where connections are made through the API to open and configure SolidWorks for opening and creating parts, assemblies and drawings. While this is going on, SolidWorks® API commands can be used to set up and exchange information with the SolidWorks program. While in the NC Programming Tab (See Figure 4) the application can manipulate and share information with FeatureCAM®. Although they are fairly complicated to understand and utilize, API's allow the functionality of the software that is available to users through the normal interface (ie with menus, ribbons, toolbars and buttons). While engineers perform their work in designing and plan the manufacture of a new component, the API programs serve as an open communication line where data important to production, marketing, customers, engineers and costing is being collected in real time. See steps in Table 1.

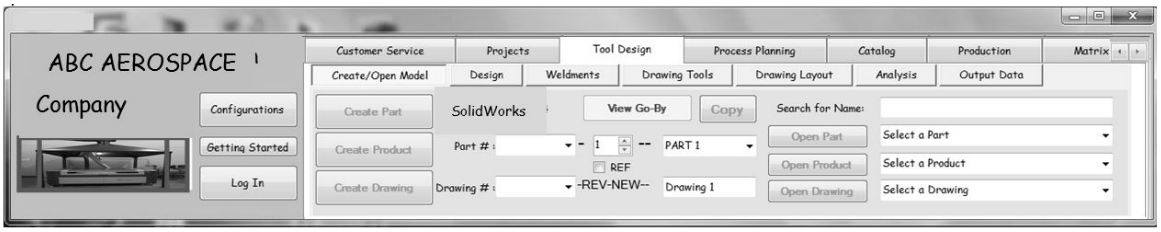


Figure 2. Main Screen where user can configure the system, log in, or begin a new job.

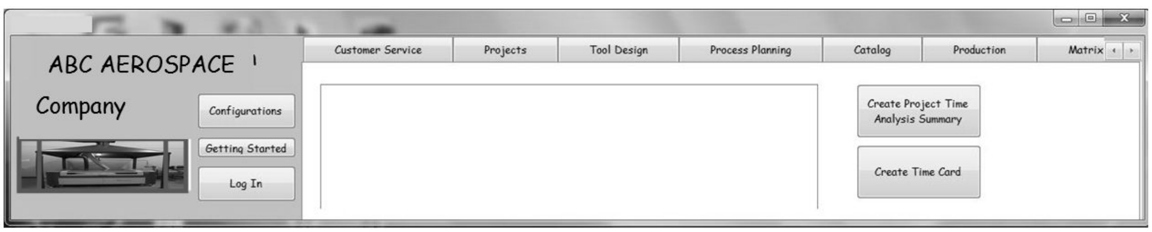


Figure 3. Component and product design module where Solidworks application and API's are initiated.

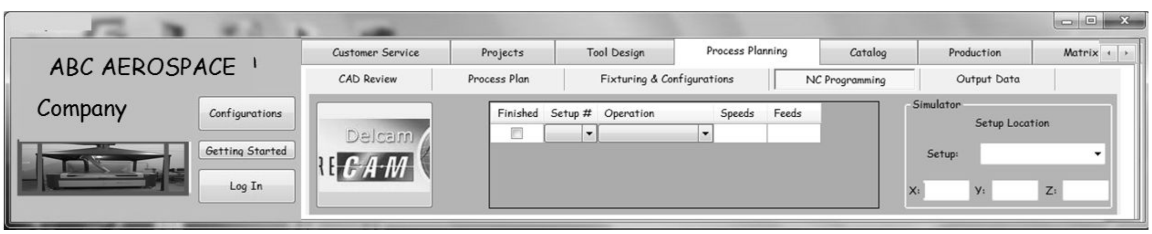


Figure 4. Process planning module where SolidWorks application and API's are initiated.

Table 1. Sequence of operations using GUI and what is the output at each step.

ITEM	API Functionality and Utilities
Open App in Visual Studio	Overall System configuration and initialization
Configuration of System Parameters and Folders	Save new configurations or pre-load saved ones
Set-up and Order for a Customer	Data storage
Open SolidWorks to Design Component/Assembly	Organize and format data
Open FeatureCAM for NC Tool Path Development	Distribute data and reports
Manufacture and Inspect Component/Product	Evaluate system performance
Finalize Product Documentation/Analysis	Feedback for improvements and learning

3.2. Case Study Outlining the Needs of ABC Aerospace Company

One of the important premises of this paper is that companies and industries have different needs, products, work methods and software applications that must be considered when looking for product data management solutions. Looking at the Aerospace industry, it generates more digital engineering data than most other industries. This data includes CAX files, MS office documents, and many other types of project information. The majority of the heavy data would be the CAX files which for example Dassault Systems provides a solution called PDM enterprise which is used to manage these files. However, most off-the-self PDM software fall short when it comes to customizable solutions for a small to medium sized business. This is not to say that these expensive software solutions cannot conform to day to day operations but have a difficult time doing so efficiently. Potentially a much more cost effective solution would entail a custom third party application that utilizes API commands in order to manipulate and extract information from primary software used every day.

At ABC Aerospace Company, custom software was prototyped and developed using MS Visual Studio. The VB.Net language was used because of its ease of programming as a higher level language and the commonality it has with primary software API's. Creating the software in Visual Studio allowed the program to act like a shell that could contain a common interface to interact with primary software used for day to day operations. Using Visual Studio also allowed employees of a company to actively develop the software for custom functionalities.

A company like ABC Aerospace generally has several departments including engineering, manufacturing, and management. Custom software that could tie information from each department together would increase efficiency by extracting data and storing it in a common database. This allows work to be done in parallel and seamlessly passes around data during different stages of development. For example, an engineer will assign a material property to a part being designed as well as specifying primary features of the part. The information in the CAD system, pertaining to material choice and feature locations can be extracted and passed on to the manufacturing engineer when working with CAM software. This can be done in the background using a shell program that is used by employees at ABC Aerospace.

An experienced employee will know more than anyone how tedious their job can be and will understand the power of automating simple tasks that are repeated every day. CAD systems like SolidWorks have allowed users to write macros using API commands from the Object Library. The same commands can be called from an outside application and can be used to perform simple tasks like creating and opening files or complex tasks like automatically modeling objects. This type of automation will save an employee many hours of work allowing more time to be productive rather than stifling creativity.

Latching on to SolidWorks from an external program can be done by declaring an object variable and calling upon the ActiveX controller for SolidWorks. For example, to initiate a new process of SolidWorks, the code would be similar to this, *Dim swApp As Object = CreateObject("SldWorks.Application").* If a process already exists the code would simply need to get the existing process, which would look like this, *Dim swApp As Object = GetObject(,"SldWorks.Application").* In both these cases the *swApp* variable can be used as a bridge to access Solidworks object library directly. The following is an example of extracting the mass property from the active model open in SolidWorks. Keep in mind the code used after the variable, *swApp*, is the same if it were used in SolidWorks VBE or from any external software.

```
'Declaring Variables
Dim nStatus as Long
Dim vMassProp as Variant

'Get active session of SolidWorks
Dim swApp As Object = GetObject(,"SldWorks.Application")

'Extract Mass property from active model
vMassProp = swApp.ActiveDoc.Extension.Getmassproperties(1, nStatus)

' Insert Bill Of Materials table
Set swBomAnn = swView.InsertBomTable2(False, 0.4, 0.3, AnchorType, BomType, Configuration)
```

The variable *vMassProp* now equals the mass value for the active model and can be used for further calculations or inserted in a report. This is an example of a simple API command; however a number of more complex commands can be used to extract almost any piece of information for SolidWorks.

Another common repetitive task that employees come across is creating reports. Most reports share commonality with formatting and require general information about a project. Automatically generating these reports can be done by using retained project information that has been added to the system previously and extracting the majority of the information for a main program. For example, this concept can be used when creating an operations list report for a CNC process. The shell program will extract the raw information about the operations list from the CAM software and can generate a customized report that is more readable to the operators on the shop floor. This type of customization generally cannot be achieved using the CAM software alone.

Customers of ABC Aerospace also need to be considered a user of the shell program assuming they have access. As information about their project is being accrued, they can receive updates in the form for a report or email. The status of a job can be extracted at various stages of design and manufacturing giving real time visibility of progress. This information can be automatically compiled in a report format and emailed or viewed as a web page.

It is important when developing a custom application to allow it to be scalable for increased functionality and for a variety of different users. A shell software that is described above gives developers the ability to easily create different interfaces for new functionality and can be customized for different users or departments in a company. Ideally this software will become web based with a single point database to relay common information among the entire company.

4. Results and Discussion

The application described in this paper represents a company process as a series of steps, represented by tabs in the GUI that take the user from Order Entry – Engineering – Flexible Data Management. Development was done by building a GUI that represented the process. Next, a skeleton functionality that allowed configuration, application access and connection of databases was built in. Once working, the individual pieces of software were connected using API commands and finally the data collection, user interactions and the overall flow were improved. Although the approach described in this paper is highly dependent on skilled computer programmers and engineers that can adjust to working closely with programmers, an effort to understand how things currently work and many months of planning and developing an architecture using a multi-disciplinary team approach, the potential exists to strive for a system that looks and acts a lot like the current system, is simple to use and one in which many things related to data collection and organization are going on in the background, hidden and of little concern to the engineers, designers, planners, NC Programmers, drafters and business personnel that make-up the set of end-users that make up the productive workforce a company.

For successful planning and subsequent implementation to occur, companies must take a multi-disciplinary and multi-departmental approach to identify where software automation and tools for streamlining product development can make the biggest impact for their particular needs and situation. Then, by combining the functionality of the CAD/CAE/CAM system with custom programs that connect an open environment like Visual Studio (C++ or VBNet) with Application Programming Interface (API) programs developed in each piece of software (i.e. Office, CAD, Web) a company could target specific areas and produce significant benefits in product collaboration and information flow. The objective is to capture, store and distribute vital information to people efficiently and present a system that can be personalized to different applications and products. Using this as a base system, there is an opportunity to grow and improve functionality as it is being implemented and tested. The idea applies to most CAD/CAM software including AutoDesk, Dessault, PTC and Siemens, among others. As a future project, the team will be considering the latest PLM/PDM that has been added to systems and determine which of them can be accessed and automated using API commands. The hope in the end is that the software has an intuitive feel that in many ways represents the company work flow and best practices.

Knowledge based systems for product engineering and business management would allow companies to embed their best practices, design/manufacturing/quality control procedures and standards developed through years of experience into the software environment that serves as the information hub for company operation. Through observation and interviews, the knowledge agent can document and model the thought process and decision making followed by design and manufacturing engineers as they operate CAD/CAM/CAE programs and resource/material management for processing customer orders. Much of this knowledge can be used to streamline and simplify operations and integrate the business and engineering functions.

5. Conclusions

Although the reality of software and other programming limitations make the implementation of the described program difficult at this time, more and more tools are being developed every day that will help researchers and engineers to continue this effort. As customers continue to have more input in the design of products they purchase, manufacturers will find way to make their systems more flexible and responsive to these changes. There are many aspects of API and software automation functionality that can be added to improve the system. Some of them include:

- Custom Graphical User Interfaces
- Easy to connect API utilities and applications to shortcuts, toolbars and menu structure for ease-of-use
- Automation of routine and error-prone processes to keep professionals focused on what they do best
- Data retrieval and CAD/CAM model database interrogation
- Configuration and setting of software parameters and attributes
- Parallel operation of programs for data management (Visual Studio, MS Office, CAD/CAM, ERP, PLM)
- With a growing PDM/PLM presence in commercial software, much of it can be included using API
- More order management, planning, scheduling and resource allocation functionality to shorten job times
- Once up and working, key users and engineers can review and suggest changes and improvements
- Knowledge Based Systems (KBS) and Artificial Intelligence (AI) play a role in product engineering

The next generation of engineers will have greater access to improved software tools that will enable them to master software/programming and Computer Aided Product Development (CAPD) to build even more integrated applications. Furthermore, the advancement of international standards and product data Application Protocols (AP's) that are part of the Standard for The Exchange of Product Data (STEP) will be helpful to make doing business across the globe much easier. By teaching concepts related to the material in this paper and doing applied research projects with graduate students, new ideas and novel approaches can be explored and discussed. In the future, software engineers and systems integration will play a growing role in collaborative and digital product development. Together these areas can work together to form the lifeline of a company (Customer Requirements – Sales – Marketing – Engineering – Production – Finance). The results can serve to train new employees, continuously improve operations and ensure that the company takes advantage of its' strengths and experience to make good decisions.

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