Session 1339

Computer Tools for Integrating Engineering Design and Engineering Economics

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Abstract

"World-class" manufacturing companies have recognized the economic importance of the decisions made during the engineering design phase of the life of a product. 75% to 95% of a product's cost is committed before manufacturing begins[i]. Initiatives such as concurrent engineering, target costing, and quality function deployment are a result of this recognition of the impact the design process has on product cost.

Major investments in new application systems are being made by just about every major manufacturer to address the Year 2000 Problem, replace old mainframe systems, and to take advantage of the latest technological advances. These new systems are replacing systems that were supporting the supply chain or order fulfilment business process.

Very few manufacturers have an integrated set of systems in place that can be used to manage the product design and change process. Very little of the massive new system investment is going into tools for these processes. This paper outlines how an integrated set of systems can be developed from existing commercial software packages. How these systems can be used to proactively manage product cost is discussed.

The Importance of Integrating Engineering Design & Engineering Economics

"World-class" manufacturing companies have recognized the economic importance of the decisions made during the engineering design phase of the product life cycle. These companies are successfully competing in the rapidly changing world market place. They have effectively implemented such initiatives as lean manufacturing, continuous improvement, total quality management (TQM), concurrent engineering, target costing, and quality function deployment.

They recognize the fact that 75% to 95% of their product's cost is committed before the product enters production (Figure 1). Target costing and quality function deployment

[1] Formally known as Sherpa Corporation

initiatives are being used to manage product cost when it is committed in the engineering design phase of the product.

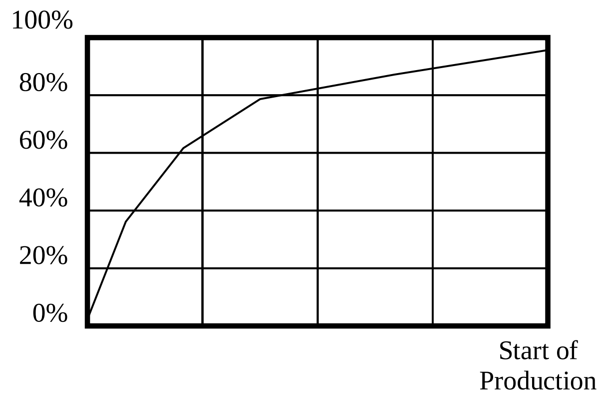

Figure 1
Percentage of Committed Cost

The successful use of lean manufacturing techniques by World-class manufactures[ii] has significantly shortened product life cycles. In the traditional market place manufacturers measured the life of a product in years. In a market place that is dominated by lean manufacturers an average product life can be as little as six months. The period of time that a product has to generate a respectable return on investment is considerably shortened**.** Figure 2 illustrates the multiple implications of the shorter economic life of a product.

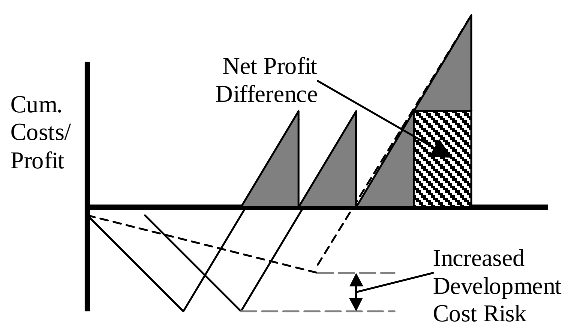

Figure 2
Impact of Product Development Time Reduction

Products must be developed quicker and more frequently while incurring less development cost to match the return of a product with a longer lifecycle.

The management of the economic impact of engineering design is becoming a critical business issue. World-class companies have successfully focused on the order fulfillment aspects of their business and now are focusing on effectively managing the engineering design aspects.

Traditional Computer Application Systems Have Significant Gaps

We are currently witnessing a massive worldwide movement to packaged software. This movement represents an estimated $52B per year investment[iii] by manufacturing enterprises throughout the world. The adoption of packaged software is driven primarily by:

- Year 2000 compliance issues – Rather than spend the money and effort to identify and correct Year 2000 problems in legacy systems that may be up to 20 years old, IS managers are implementing packaged solutions that have been certified as "Y2K" compliant.

- The move to client/server systems – In the last ten years the basic architecture of computer systems has shifted from mainframe and minicomputer systems to three tiered client/server systems. This shift obsoletes legacy systems built on the older architecture. The adoption of packaged systems built on the client/server architecture offers an opportunity to move to client/server architecture and take advantage of the latest developments in software and hardware technology.

- The downsizing of the information services function – The corporate downsizing movement of the late 80's and early 90's has had significant impact on the information services function. The large IS staffs required to write and maintain custom application systems are a luxury only a few companies can now afford. The use of packaged software eliminates the need to write custom code and reduces the resources required to maintain the systems.

The movement to packaged software can be considered essentially a replacement market generated by technological needs with few advances in business or application functionality. The functionality that has evolved over the years is being replaced on a one for one basis. This functionality includes:

- Order fulfillment from sales support through order entry to customer shipment
- Distribution logistics (Supply Chain Management)
- General accounting and finance
- Customer service and field engineering

The term enterprise resource planning (ERP) has evolved to cover the packages addressing the above functional requirements. Are the ERP packages covering all the functionality needed to support a company's business processes and information needs? What are the functional gaps?

Despite the general acceptance of the ERP vendors' claim that they address all the needs of a manufacturing enterprise, significant gaps exist, such as:

- The management of the product development and change process. ERP packages do not adequately address the needs of the product development and change process. An ERP system primarily focuses of the order fulfillment process. It is assumed that product development has taken place and there is a released, stable definition of the product and production process. While there is functionality that can be used for engineering design, such as the Bill of Material Generator, an ERP system does not provide the full functionality that is required to organize, manage, and control the product development process.

- Support of critical business initiatives - Business initiatives critical to meeting a company's goals and objectives such as Target Costing, Quality Function Deployment, Continuous Improvement, TQM, Management of Intellectual Assets, etc. addressed with informal or standalone systems, if at all. There is very little functionality in an ERP system that can be used by these initiatives.

- Engineering economics and the engineering design process - The application of good engineering economics to engineering design has been inadequately supported. The accumulation of the necessary cost information, calculation of target costs, management of actual to target costs, management of engineering change costs, the cost of designing products, and the management of product life cycle costs remain primarily manual processes supported by informal and non-integrated systems.

Functional considerations aside, do the ERP centric packages address all of today's business issues? The great majority of older, legacy systems can be characterized as large, monolithic, and tightly structured with code that has evolved over a large number of years. Such systems are difficult to maintain and require a high level of effort and time to change. These systems are difficult to modify when a company's business requirements change and can become a hindrance to a company's overall ability to respond to change.

The newer ERP packages have attempted to address this situation by using tightly integrated functions. System efficiency and maintenance has been improved, but the need for flexibility has been only partially addressed by using the concept system configuring. System configuring as a means to adapt packages to different business environments can be very effective in structured business environments that reflect traditional ways of doing business. This is because the alternate business environments that they address must be predefined. Most manufacturing companies today are facing rapidly changing business environments that they must meet with totally new ways of doing business (thinking out-of-the-box). Their design engineering processes, which have always been very non-structured, must now quickly react to rapidly changing design requirements. For these companies, even the newer ERP packages fall short.

Computer Application Architecture

The functional gaps in existing computer systems can be closed without writing extensive lines of computer code. The use of a loosely integrated computer architecture built on a customer's legacy systems and employing readily available packaged applications can rapidly close the gaps and start generating significant business benefits.

An ERP system is an example of a tightly integrated computer architecture. ERP software vendors attempt to provide the solution to all an enterprise's application functionality requirements in one package. Much of the logic for the various business functions is very interwoven and shares a common database. If an enterprise requires additional functionality, there are three options:

- Wait until the software vendor incorporates the functionality into the next release of the software.
- Write code that is unique to the enterprise and not supported by the software vendor in the standard package.
- Where possible, obtain packages that meet the functional requirements and integrate with the ERP using the ERP's API's (Application Programming Interfaces) and their standard interface protocols.

The loosely integrated computer architecture is based on modular applications that interrelate using commonly accepted computing standards. This architecture is based upon:

- Three tiered client/server – The system user interface, application business rules, and data management functions are separated into three tiers (Figure 3). Each tier addresses specific business and technical requirements. As the requirements unique to a specific tier change or expand it is possible to incorporate the change within the tier with minimal or no change to the other tiers.

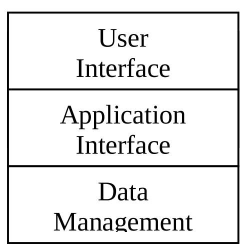

Figure 3 – Three Tiered Computer Architecture

- Brokered object oriented integration – Rather than very tight (hardwired) integration, a looser integration using brokered communication between objects[iv]. The objects can be defined in a very specific manner, such as part, drawing, etc. or very grossly. A large system like an ERP can become a very gross object when "wrapped" to look and behave like an object. Communication between the objects is facilitated and managed by an object broker. Two of the most commonly recognized object brokers are the OMG's CORBA and Microsoft's OLE.

The business functionality necessary to close the gaps can be assembled using commercially offered application packages[v]. Figure 4 represents the different types of application software packages that could be used by a typical manufacturing company. The specific package mix and what packages are considered business critical depends on the company's business environment and critical business issues.

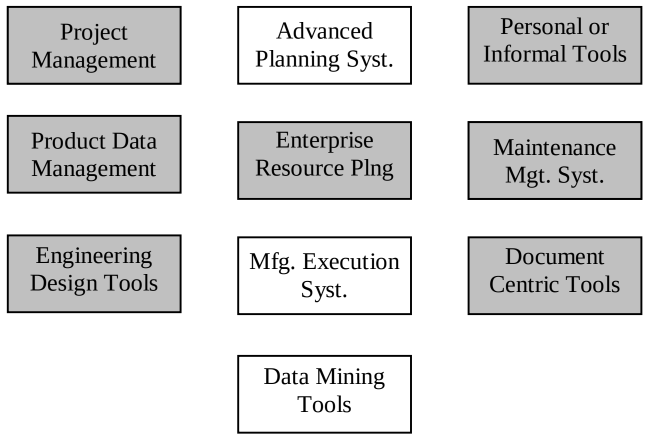

Figure 4 – Typical Manufacturing Computer Environment

The following details those systems (the gray shaded boxes in Figure 4) that can be used to address integrating engineering economics and the engineering design process.

- Enterprise Resource Management (ERP) Systems – Over the last forty years ERP systems have evolved from a Bill of Material (BOM) generator through Materials Requirements Planning (MRP) and Manufacturing Resource Planning (MRPII) systems by increasing and adding business functionality. This evolution has been closely mentored by the Oliver Wight Organization and American Production & Inventory Control Society (APICS). As a result, the majority of the ERP packages on the market provide a very consistent set of functions and conform to basically a common system architecture. Figure 5 shows functional modules of a typical ERP system. The application of engineering economics to the engineering design process would interface with the Manufacturing Resource Planning (MRPII) module.

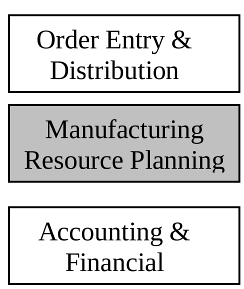

Figure 5 – Major ERP Modules

Manufacturing Resource Planning (MRPII) now represents only the functions that are required to plan and schedule the resources to manufacture the product. These functions that impact the engineering design process include:

- Inventory Management – The Inventory Management function defines the inventoried items (item masters) and manages the physical inventory of these items. The Inventory Management function maintains the product and component item master. This item master contains the information necessary to plan and schedule production. The information includes item or part number, revision level, description, unit of measure, order lead-time, quantity on hand, quantity on order, make or buy indicator, standard cost, and actual cost.

- Bill of Material Generator – Product structure is maintained by the Bill of Material (BOM) Generator function. This function is not a list or "picture" of the structure. It maintains the hierarchical relationships between the various components of the product. Whenever a product structure is required, it can be created by the BOM Generator. This capability provides an extremely effective tool for managing multiple product structures and is the engine that drives the Material Requirements Planning (MRP) function.

- Material Requirements Planning (MRP) – The power of a MRPII system is its ability to plan and schedule the manufacture or purchase of the product and its components over time. Every product order generates a dependent demand for its components. These components, in turn, generate a dependent demand for their components. This process continues until the last purchased material item at the lowest level of the product bill of material is reached. The MRP uses the BOM Generator to "explode" or find the required components and using each component's order lead-time calculates when it must be in stock. This is done for all product orders. The result is a time phased schedule of when components should be ordered tied into the demand for the final products.

- Purchasing – The MRP generates a requirements plan that recommends when and how many purchased components should be ordered. The appropriate buyer uses the Purchasing function to create a purchase order. This order can be sent to suppliers by mail or electronically using Electronic Data Interchange (EDI) protocols. When the component is received, the purchase order record is accessed, the shipment is inspected & accepted against the order, and the component entered into inventory.

  The Purchasing function generates firm orders for all purchased components and captures their actual costs.

The majority of the ERP packages address the discrete manufacturing environment. The process industry is served by:

- Discrete ERP packages modified to address process manufacturing issues.

- Formula based packages that use the basic MRP time phased demand planning and replace the BOM logic with logic that meets such unique requirements as multiple end products and by products.
- Custom planning systems based on a spreadsheet format and raw material yield formulas.

For the purposes of this paper the term ERP will apply to both discrete and process manufacturing.

ERP systems are based on transaction or "bank teller" logic. For example, the inventory function acts as the bank. Products and components are requisitioned from the inventory and sent to the inventory using withdrawal and deposit types of transactions.

This logic creates heavy transaction or input/output (I/O) demands on database and computer systems. These systems are optimized to provide the most efficient processing of transactions that use relatively little main processor and communication time and resources. Mass storage is organized to provide the fastest access to small amounts of data. Functions that require significant processor (such as simulation and statistical analysis) and communication bandwidth & storage (such as CAD and document management) are generally provided as add on peripheral systems.

- Maintenance Management Systems (MMS) – Maintenance Management Systems support the maintenance and repair of capital equipment. Some ERP systems include MMS functionality. The majority of the ERP systems provide API's to facilitate tight integration to commercially available packages. Most MMS systems are designed to support fixed equipment used for manufacturing or associated with the physical plant. Some MMS packages have been used to support field and depot maintenance of major transportation equipment, such as aircraft (civil & military), railroad rolling stock, and ships.

  A MMS system consists of three functional parts:

  - Job Ticket Management – When unscheduled maintenance is required a job ticket is created, resources assigned to the job, resources and replacement parts used recorded, and the job is closed out.

  - Scheduled Preventive Maintenance Planning and Execution – The scope of the scheduled maintenance is defined, resources planned & scheduled, resources & replacement parts used recorded, and maintenance project is closed out. A maintenance planner can access previous unscheduled and scheduled maintenance records and available replacement parts in the MMS. Other information, such as drawings, specifications, and what was produced by the equipment usually have to be accessed in other systems or from paper records. The scheduled work is broken down by mechanic skills into a series of interrelated jobs and that are individually managed by the Job Ticket Management function.

- Resource Inventories – The MMS maintains an inventory of replacement components. Each mechanic's skills, certifications, and availability is also maintained.

A variation of a MMS system is the Field Service system. This system has essentially the same functional elements, but focuses servicing customer owned product. Logic that manages service agreements and customer billing usually an integral part of this type of system.

MMS & Field Service packages are transaction bases systems sharing many functions with ERP systems.

- Project Management Systems – Project Management Systems are used to plan, organize, and manage major non-repetitive programs. A Project Management System can be used to support new product development, custom engineered orders, and the building of major equipment (ships) and facilities (refineries).

  A Project Management System can be used to create a work breakdown structure of tasks. Each task can be assigned to individuals or groups of individuals. Each task has finite deliverables with a scheduled completion date. Most systems will identify the critical path or the series of tasks that will take the longest to complete. Resources are associated with and allocated to tasks.

  As program tasks are completed; the completion date, resources used, and material costs incurred are inputted into the system. The system is then run on a batch basis to update the schedule, recalculate the critical path, and accumulate the costs of resources and materials.

  A Project Management System uses logic that is very calculation oriented that uses large amounts of central processor resources. The task status information usually is not integrated to any existing source of data. Data associated with the tasks is usually manually inputted. As a result a Project Management System is usually not routinely refreshed or updated. Updates usually run when a major milestone occurs or there is a significant change.

- Engineering Design Tools – These are electronic tools that are used by design engineers to create new products. Generally these systems fall into the following categories:

  - Mechanical Computer Aided Design (MCAD) – This is a set of design tools that are used to develop the mechanical aspects of a design. The tool set consists of numerous modelling sub-routines, special libraries, and high-resolution graphical user interfaces.

  - Electronic Computer Aided Design (ECAD) – ECAD is a set of tools to design the electronic circuits and functionality that go into the product. This tool also uses modelling sub-routines, special libraries, and high-resolution graphical user interfaces.

- Computer Aided Software Engineering (CASE) – CASE supports the orderly development of software. CASE tools enforce language and structured programming practices, manage the code creation, and maintain the released software.

Engineering design tools are compute intensive systems that are manipulating massive amounts of data in the computer's central processor. Each of the three tool categories have separate architectures, data constructs, and databases. These are essentially standalone, "stovepipe" systems that are focused on optimizing the aspects of the design process they support not on the integration of various design elements into a single product.

- Document Centric Tools – Document Centric Tools provide a way to author or capture published documents in an electronic format. Microsoft Word is an example of commonly used Document Centric Tool. The contents of a document record are generally unstructured and can be in multiple formats. The more sophisticated tools provide a way to electronically construct documents using such protocols as SGML and XML.

  Advanced Document Centric Tools provide a way to universally distribute the electronic documents in a format that the end user needs. The Web is becoming a very effective way to accomplish electronic document distribution. Content browsers provide the ability to search the content of documents for specific information.

- Personal or Informal Tools – These tools provide basic computing functionality. The entire Microsoft Office suite of tools, with packages like Excel, Access, Project, Visual Basic, etc. is an example of such tools. An application can be quickly developed and implemented with these tools. Unfortunately, these applications are usually not integrated with other applications and must be maintained outside the corporate IS infrastructure.

- Product Data Management (PDM) Systems – A Product Data Management system provides the following functionality:

  - Process Management – PDM workflow functionality provides a means to manage the processes that create and change product & manufacturing process information. The PDM workflow is based on the concept of create, review, and release and does not micro-manage individual work activities within a process. This concept corresponds to the tasks defined in a work breakdown structure that is developed for large projects or programs. Tasks to create specific deliverables can be defined and assigned to a responsible organization or individual with a scheduled completion date in a Project Management system and electronically sent to the PDM system for execution.

The PDM workflow manages the execution of the tasks. Each task will have its own requirements for the review, approval, and release of its deliverable. Individuals and functions responsible for the review, approval, and release of the deliverables can be pre-assigned. When a deliverable is completed, the individuals responsible for its review are automatically notified. In turn, when the deliverable has been reviewed by all responsible individuals, the individuals responsible for approving are automatically notified. The ability to assign tasks that correspond to the work breakdown structure, define the release steps for the deliverables, and have events automatically "trigger" the next step provides a means to manage and control the process. This workflow logic provides a very effective way to manage unstructured, non-repetitive processes, such as new product design and change where individual activities are not easily defined.

- Document Management – The Document Management function in an "enterprise" PDM system does more than manage documents. The original use of this functionality was to manage the documents that defined the product, which were usually drawings generated by a Mechanical CAD system. Today the Document Management function manages all "objects" that define and provide information on a product. These objects include MCAD drawings, ECAD schematics, CAD models and design elements, design specifications, standard operating procedures, software (including product, test, NC, PLC, process control, and robotic code), process instructions, tool designs, process routings, and any other information that relates to the product.

  The Document Management function was originally developed to eliminate the need to create a hardcopy master drawing or "vellum". The electronic documents created or changed by MCAD systems were being printed immediately upon release and sent to a Document Control organization for "vaulting" and distribution. Whenever the most current released version of a drawing was required an individual had to request a print from Document Control. The PDM Document Management function performs the same function for electronic copies of released drawings and all other business critical product information that must be managed and controlled.

  Once a document or any information object is released by the Workflow function it is automatically vaulted by the Document Control function. Those individuals who must have copies of the released document are automatically notified and can electronically access the new or revised document. When anyone with a need to know accesses the document they will view the latest released copy.

  The PDM Document Management function uses the concept of a meta database that stores summary or attribute information of the individual objects and maintains electronic pointers to the "source" system where the information objects exist. When a person accesses an information object, the PDM system will go to the source system and open up a "view" of the object using the source system programs. The PDM system doesn't store the information objects and does not need logic to view the information. This capability makes it possible to access and view product information rapidly from any database and in any format.

- Universal Access to All Critical Product Information – One of the problems with the hardcopy based Document Control concept and organization, was the restricted access to product information. To maintain control, the Document Control organization had to restrict access to the master copy and create a mechanism to provide copies to only those individuals with a need to know. The PDM Document Management function provides the ability to access electronically controlled information and the security to ensure only those individuals with a need to know can access the information. To take advantage of these features a PDM system must provide a way to quickly find the information and once found to view the information with the common desktop computer tools, such as Microsoft Windows and the various Web Browsers.

  Quick access to the information is addressed in two ways:

  - Finding the Information – For information to be useful it must be readily and quickly accessed. PDM provides several ways to access the product information:
  - Item Identifier – All objects stored in the PDM vault are uniquely identified. Part numbers or a drawing numbers are examples of such identifiers.
  - Attribute – Information objects can be found by describing a key attribute. The PDM Meta Database contains key attribute information for all vaulted objects. A key attribute could be a part description or physical attribute, such as hex nut.
  - Structure – The next section discusses how PDM manages product structure. It is possible to "walk" a product structure to find a component and then transverse to another object structure to find all the information associated with the component.
  - Image – Advanced PDM systems provide the ability to find information by "clicking" on an image or picture of the product or component.

- Rapid Presentation of the Information –To be a useful the information must be presented without a significant delay. This presents a problem for the type of information that PDM system manages. The average file size of this information is usually very large. Large files can be slow to access and transfer from the server system to the client, especially if they have to be communicated over long distances. A PDM system provides the ability to duplicate and locate the native systems and their files anywhere in the world, eliminating any communication delays. A user in Singapore may access a PDM system in San Francisco and end up viewing information that is maintained in a system in Singapore. The information in the Singapore system may be updated over night on a batch basis. The PDM system will manage this update and ensure the source system database is always current.

- Product Structure – PDM systems have a Bill of Material (BOM) Generator function that is identical to the ERP BOM Generator with two important exceptions. The ERP BOM defines only the planned BOM and only material (i.e. the product and its components as defined by an item master). A PDM system manages the entire product life cycle structure, e.g. as-proposed, as-designed, as-planned, as-built, and as-maintained. The PDM BOM Generator is used to structure part, document, software, model, manufacturing process, and any other controlled product information object. Each object can have its own hierarchical structure and "transverse" linkages to individual objects in other object structures.

  The PDM BOM Generator logic makes it possible to:

  - Develop product specifications representing specific functionality and link the specifications to design specifications and eventually to individual components of the product. When a product function is changed it only the design specifications and components directly linked to the function need to be changed. This ability can be a very useful tool for making functional trade offs when target costs are exceeded during the design process.
  - The processes required to manufacture the product can be linked to each component of a product. The all the information needed to manufacture the component can be assembled in one place and managed.
  - The as-planned bill of material and item master can be created and changed in PDM and electronically transferred to the MRPII function of an ERP. The PDM BOM Generator functionality combined with PDM Workflow functionality makes it possible to involve all the appropriate manufacturing personnel in the development and change process at a much earlier point in the release process. This early involvement is the cornerstone of the Concurrent Engineering and Integrated Product Process Development (IPPD) initiatives.

- Product Configuration – The functionality outlined above makes it possible to create and manage product configurations. The configurations relate all controlled information to the product and its components. The net result is a very complex set of relationships that resemble a molecular structure (Figure 6). This structure is created in an evolutionary manner as an integral part of the product development process. Once created the product configuration is subject to change. A PDM system manages product configuration by:

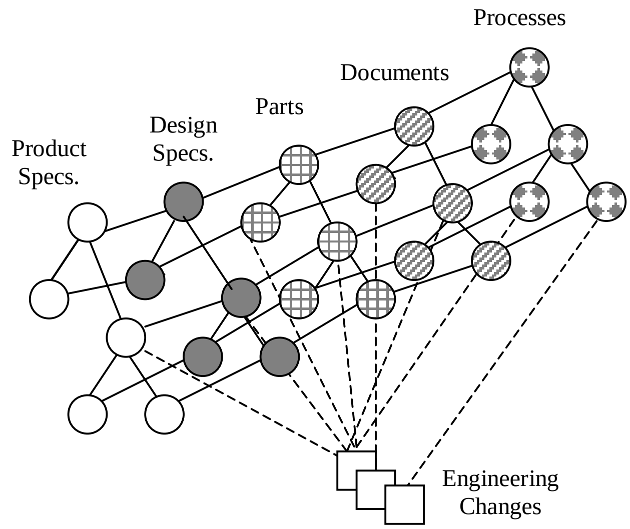

Figure 6 – Product Configuration

- Baselining - The various stages of the product configuration evolution is captured using the concept of baselining. Baselining is essentially a snap shot of the product configuration at different phases in it life cycle, such as as-specified, as-designed, etc.

- Engineering Change – All change to a configuration is managed by the PDM Engineering Change logic. This logic is essentially a combination of the basic PDM functions that results in a record of the change linked to the objects that were changed. It is possible to determine what objects were changed or revised by the change action, what changes actions applied to specific objects, the rationale for taking the change action, and who was responsible for the change action.

A PDM system uses Object Oriented concepts. These concepts make it possible to access information that exists in different formats wherever it may exist and create meaningful relationships between the information objects. Workflows that address the creation and change of objects can be defined to mirror the "real life" processes that create physical objects.

The object orientation of a PDM system represents logic that is not easily incorporated into transaction based system such as an ERP or compute intensive system such as CAD. However, it is possible to incorporate transaction and compute intensive systems into the object oriented architecture.

Using Existing Computer Tools to Integrate Engineering Design and Engineering Economics

The examples in the following sections address how loosely integrated application packages can be used to focus on managing the product development and change processes and facilitate the integration of engineering economics and engineering design.

- Effective Target Costing – Target costing has emerged as an important tool for addressing product cost early in and throughout its development life cycle. At the product conception stage a target cost that will yield the desired profit is quantified. As the product proceeds through the multiple stages of its development, the estimated cost of the product established and compared to the target cost. If the estimated cost is greater than the target costs, component costs are reviewed and a number of actions can be taken, including:

  - Replacement of a high cost component with a lesser cost component with the same form, fit, & function.

  - Outsourcing components to suppliers that can produce them at lower cost.

  - Eliminating higher cost components by reducing product functionality.

  - Discontinue development of the product.

  The integrated system can be used to facilitate target costing and effectively manage product costs. Few new products are designed without using existing components. At the time of product conception the PDM system can be used to create the new product by copying an existing product structure with all its related information to the identifier or part number of the new product. The copied structure would be reviewed and the components classified in the following ways:

  - Reused – These are the components from the existing product that will be reused in the new product. The related information managed by the PDM system can be used in its entirety. This information will include the product's standard or actual cost (depending on the company's cost accounting practices). A confidence factor field could be created in the PDM cost record to indicate the firmness of the estimate. In this case the factor would be 100% indicating the use of costs based on actual purchases and production experience.

  - Modified – A number of existing components must modified before they can be used in the new product. In most cases the existing component and all its supporting information will be copied over to a new component part number. Once copied the information can be reviewed, changes identified, and its cost estimated with a confidence factor. As the design modification progresses the estimate can be changed and the confidence factor increased until it is 100%.

- New Design – A percentage of the old product's components will not be used and completely new components will be designed. The components that will not be used are deleted from the new product's structure and the new component part numbers added. At this time an estimated cost with a confidence factor will be added.

For each modified and new design component a work breakdown structure of the design tasks will be developed. Included in these tasks will be tasks to review and update the estimated costs. All tasks can be planned and scheduled in a Project Management system and electronically transferred to the PDM system for execution. The task execution is managed by the PDM Workflow functionality. The estimating tasks are "triggered" when key deliverables, such as the completion of a material specification or tooling design, are released.

A simple cost review task could be triggered when a material specification is released. A buyer within purchasing would assigned the task, obtain the cost quote, update the PDM material cost record, and close out the task.

Estimating the manufacturing costs of a major component subassembly would be a more complex task. This type of task would be triggered when enough information is available to start defining the manufacturing process. A series of progressive tasks may be required. As soon as the most basic information is released the appropriate manufacturing and cost accounting personnel are automatically notified, a preliminary estimate is created, the PDM manufacturing cost record is updated, and the task is closed. As more information is created a new estimating task is triggered, the manufacturing estimate is improved and the confidence factor increased. This sequence of tasks is repeated until the confidence factor reaches 100%.

The use of progressive estimating tasks ensures the early participation of "downstream" manufacturing personnel such as manufacturing engineers, material managers, buyers, product planners, and cost accountants. Design changes to improve the manufacturing process and meet or "beat" cost targets can be made as soon as possible in the design phase

The PDM Bill of Material (BOM) Generator can be used to "roll up" the material and component costs. Costs will be generated for the product and all its major components. When a material or manufacturing cost estimate is changed, the BOM Generator will be triggered to roll up the costs, and create new product and component cost estimates.

Using loosely integrated application packages to facilitate Target Costing process will provide to ability to:

- Implement Event Driven Target Costing – A target costing process that is manually based or uses standalone computer systems requires a significant amount of time to develop the cost estimates. Because of this, the target costs are compared to estimated costs only at significant points in the product development process. The use of PDM integrated to a spreadsheet, such as Excel that is based on Microsoft Foundation Classes & OLE can provide the ability to continuously monitor estimated costs.

When the BOM Generator initially rolls up the product and component costs the resulting costs and their confidence factors are automatically transferred to an Excel spreadsheet. Target cost for the product and components are added. The Excel spreadsheet is checked into the PDM system and becomes a controlled document that is associated to the new product as a permanent information record. Whenever a cost estimate is changed, triggered the BOM Generator to roll up the costs, and automatically update the Excel spreadsheet. If the new estimates exceed the target cost, the appropriate program managers are electronically notified. They can immediately access the spreadsheet and take action to bring the product back to or below target.

- Relate Component Cost to Function – The PDM system can be used to manage the product concept process and capture the resulting product specifications. If these specifications are broken down into modules that are directly related to product functionality, product functions can be directly related to individual product components using the PDM transversal logic (Figure6). Whenever, a component is identified as exceeding its target cost, the product functionality that it provides can be immediately identified and the impact of reducing functionality assessed.

- Time to Meet Target Cost – When the product is released to production, all the individual estimated costs ideally should have a confidence factor of 100%. The next challenge is to manufacture the product to the target cost. A measure of the effectiveness of the target costing effort is how long it takes for the actual cost of manufacturing the product to equal the target cost. Initially the actual costs should be higher than the target costs for a number of reasons, including:

    - Operator learning curves
    - Supply chain establishment & stabilization
    - Process tuning
    - Design and document errors

  If the downstream manufacturing personnel actively and effectively participated the early stages of the development process the initial production disruptions caused by these factors should be minimal and quickly resolved. This participation is reflected in the initial difference between the actual and target costs and how long it takes to bring them into parity (A & B respectively in Figure 7).

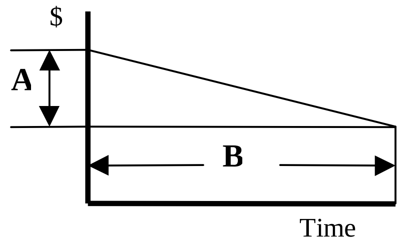

Figure 7 – Time to Meet Target Costs

Actual costs to manufacture the product and its components can be captured by the ERP system or equivalent manufacturing system and electronically transferred to the PDM system. This transfer would trigger an update to the product Excel spreadsheet. The spreadsheet can be set up with columns that represent the actual costs by week. Charts similar to Figure 7 could be created and automatically sent to the product manager and any other interested individuals.

- Management of the Cost of Change – Every product and manufacturing process change has the potential to impact the cost of the product. The integrated software can be used to manage the cost impact of change in two ways:

  - Quantifying the Cost Impact as Part of the Change Process – The change process can be managed by PDM. An electronic change form (such an Engineering Change Order) can be created in PDM, all associated information attached to it, and a PDM change workflow initiated. The change is automatically routed to the appropriate individuals for analysis, review, approval, and release. An individual, usually in manufacturing or cost accounting, is responsible for quantifying the cost impact of the change. This individual will be able to review the change in the PDM system, determine the impacted components, and trigger the electronic transfer from the ERP system to the PDM system of specific component & material costs, demand, and number of units on hand and on order. This information can be transferred to an Excel spreadsheet for the calculation of the cost impact. The spreadsheet is then vaulted and electronically attached to the change form as part of the supporting documentation.

    The cost of any replacement parts or additional manufacturing process steps can be determined and the appropriate product or component costs updated in the new, to-be released version of the product. The PDM BOM generator can roll up the costs and update the Excel spreadsheet that was created to manage target costs. If the revised costs exceed the target costs, an alert will be sent to the appropriate individuals.

  - When Change Occurs – A formal change process, such as an ECO, is usually associated with product that has been released to production. Because the cost of change increases almost geometrically from the time a product is conceived to its release to production[vi], many companies have been implementing a formal, but simplified change process throughout the development cycle. The PDM system is used to facilitate and capture these changes. Cost of these changes can be estimated and reviewed as part of the change process.

Using charts generated by the PDM system management can, for each individual development program, review when change occurs and take action the appropriate action to move the critical mass of changes to the earlier part of the development cycle.

- Product Value Engineering – The management of the change processes with PDM offers an opportunity to implement an enterprise wide value engineering program. Value engineering opportunities can be identified and reviewed using the change process. The electronic change form can provide an area for identifying recurring problems. This area could contain a list of specific quality attributes, such as rust on the frame, miss fitting doors, etc., with a blank space for additional attributes. The PDM system can periodically scan the change forms and generate a Pareto list that ranks the attributes by the their frequency of occurrence. A value engineering project could be opened to address the chronic quality problems.

- Optimization of Manufacturing Equipment and Tooling Investment – The integrated systems can be used in two ways to optimize the cost manufacturing equipment and tooling investments:

  - Target Costing – The approach for product target costing can be used for manufacturing equipment and tooling. In process and fabrication oriented manufacturing companies these costs represent a significant part of the total product costs.

  - Concurrent Equipment and Tooling Design – The ability to link equipment and tooling design tasks to individual components and design elements tasks means the design effort can be initiated at the earliest possible time. Often equipment and tool design must wait until the product or component design is released. With PDM the completion of the critical components or design elements will automatically trigger the equipment and tooling design.

- Total Product Life Cycle Costing – Traditionally companies have focused on the manufacturing costs. Investments in ERP systems are justified on the basis their contribution to managing and reducing production & distribution costs. ABC accounting capability incorporated into the more advanced ERP systems is providing a way to quantify and associate many of the costs that have been traditionally written off as overhead directly to product costs. The quantification, management, and association of the cost of non-structured, non-repetitive work, such as design engineering and customer support to the product remain a challenge. The loosely integrated system approach can be used to address this problem:

- Design Engineering Cost Management – The cost of product development is traditionally written off as a general overhead charge. For major development projects a Project Management system linked to a Labor Reporting system and an Accounting function that reports project expenses may be used. Even in this case the cost of developing actual components is usually hidden in the overall project costs.

  The ability to create individual tasks with deliverables in a Project Management (PM) system and automatically transfer these tasks to a PDM system offers the opportunity to capture and associate development costs directly to product components. A task or series of tasks can be created with a deliverable of a released component. The Project Management system can accumulate the development costs to individual tasks. These costs can be electronically transferred on a batch basis or as they occur to the PDM task records. The PDM BOM Generator can roll up each task cost to the task that releases the component. Transversal logic can be used to transfer the cumulative task development costs to the component record.

- Customer Service Cost Management – In some industries the cost of customer service can be significant. How these costs are managed and recovered in respect to the initial purchase cost of the product can be a critical business issue. In highly competitive industries, such as the commercial aircraft industry, the intense competition often means the product is sold with very little profit margin, if at all. In these industries significant profit margins have to be generated in post delivery customer services and logistics support. An integrated system can be use to effectively manage the customer product configuration with its associated information and manage costs in the following areas:

  - Accumulation of Maintenance Costs – When a maintenance cost record is generated in a Maintenance Management or Field Service system against a product or component, it can be automatically transferred to a cumulative maintenance cost record of the product or component in the PDM system. This cost can be readily accessed on demand and reports generated that identify those products and components that are incurring significant maintenance costs. If more detailed information is required the PDM system, the user can at the "click of a mouse" automatically link to the detailed information in the MMS system.

  - Efficient Use of Resources – A PDM system in conjunction with a Maintenance Management/Field Service system will, on demand, efficiently provide field engineers with the information they require to maintain the specific configuration of the customer's product. Personal efficiency of the field engineer increases and they become more effective using readily available information, driving the cost of maintenance down.

  - Efficient Management of Logistics or Field Inventory – The impact of product and component changes on delivered product can be evaluated. The PDM change review workflow can be set up to notify the Field Service group whenever a change to the product they maintain is initiated. Maintenance Management/Field Service system records of customer product can be accessed and the impact of the change evaluated and added to the electronic change form's manufacturing impact analysis spreadsheet.

Periodically, obsolete material inventoried for Field Service use can be identified by generating component end item used on lists in PDM and electronically comparing these lists with the listing of product Field Service is maintaining in the field. Where is no match or only a few products are still in operation, the components are candidates for write off as obsolete material.

- Product Life Cycle Cost Management – It is now possible to accumulate the total costs associated with a product during its life cycle. Target costs can now be accurately tracked and effectively managed in the development cycle and during manufacturing. The impact of product change can be managed, documented and the target cost updated. The cost of manufacturing the product can be calculated on an ongoing basis. The added costs of maintaining shipped product can be accumulated.

  The PDM system can accumulate all these costs directly or through integration to other systems (Figure 8) and provide the total accumulated product cost information on demand at any point in its development cycle. A "snap shot" of accumulated costs at critical points in the product's lifecycle can be archived using the Baselining functionality.

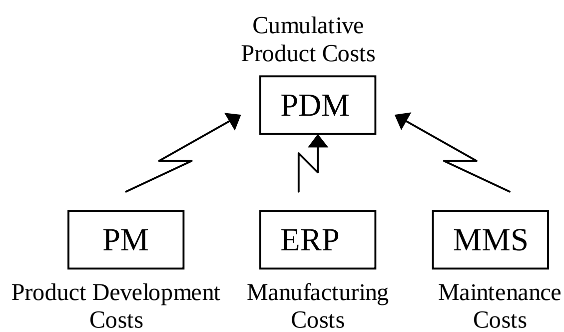

Figure 8 – Automatic Accumulation of Product Life Cycle Costs

Combined with product sales & maintenance revenue data it is now possible to fully chart the profitability of a product (Figure 9) over its entire life cycle.

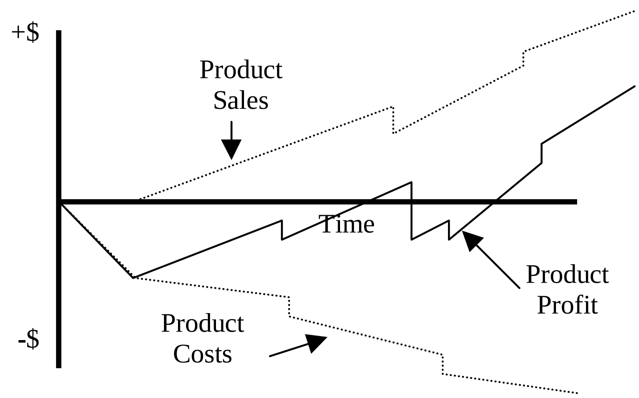

Figure 9 – Tracking Cumulative Product Profitability over Its Life Cycle.

Conclusion

What we are witnessing is a classic case of the power of momentum. The investment in computer systems that address manufacturing and supply chain business issues has grown at a far greater rate than the incremental savings they yield. Fifteen years ago investing more than a million dollars in a computer system such as an ERP was not very common. Today companies are investing $10-$30 million dollars for essentially the same types of systems without question and little consideration to their net return on investment.

World-class companies have recognized the need to address the engineering design process. Integrating engineering economics with the engineering design process can provide all management levels of a manufacturing enterprise the focus they need to use the design process to drive significant business benefits. The use of loosely integrated commercial computer systems makes this integration possible.

Management's focus and investment on the order fulfillment process has created significant business benefits for the world's manufacturers. Yet there are still significant business issues and challenges to be addressed. It is now time to shift the focus and investment to the engineering design process.

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Bill Bambrick is a Business Metrics Consultant for the PDM Division of Inso Corporation. He is responsible for working with Sherpa's prospects and customers, helping them justify the business benefits of PDM, reengineer their processes to maximize the return on implementing PDM, and establish operational metrics and measurements to manage the processes supported by PDM. Prior to joining Sherpa, Bill was a Manufacturing Consultant with Digital Equipment Corporation for 9 years. In this position he advised Digital prospects and customers on enterprise wide solutions from Product Development through Manufacturing to Customer Distribution. Before Digital he spent 20 year architecting, developing and maintaining information systems for leading electronic, aerospace, and petrochemical operations. He holds a Bachelor of Engineering from Stevens Institute of Technology with honors and Masters of Business Administration from the Wharton School, University of Pennsylvania.

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[i] D.E. Whitney, "Manufacturing by Design", Harvard Business Review, (July/August 1988):83-91.
[ii] Robin Cooper, *When Lean Enterprises Collide*, (Boston:Harvard Business School Press, 1997)
[iii] Estimated by AMR Research, Inc., Boston, MA
[iv] For a very good overview of object oriented technology see *Object Technology, A Manager's Guide,* by David A. Taylor (Reading, MA:Adison-Wesley, 1998)
[v] Because the commercially offered application packages reflect the functionality of custom written legacy systems the following discussion generally applies to manufacturing companies with custom written application software.
[vi] "*A Smarter Way to Manufacture", Business Week* (April 30, 1990):110-117