MODELING AND USE OF COMPONENT INFORMATION IN THE PROCESS INDUSTRY

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1 ABSTRACT

This in-process research project investigates the life-cycle information requirements for the components[3] which are installed in process plant facilities. We have done this to gain insight into existing standards efforts and to understand the content requirements for the development of standard information models that represent such components. This work seeks to understand how these information models may be used to improve business and technical work processes through the development of software applications which support information sharing between component design objects rather than information exchange between design documents.

2 INTRODUCTION

Currently, effective and timely exchange of information about the components which go into process plants is an important business problem. Given a set of engineering requirements, vendor knowledge often drives component specification for facility design and engineering and, as well, the procedures for component installation and maintenance. Designers and engineers require accurate and timely access to this information. However, effective and accurate exchange of component information requires non value-added effort to access, interpret, validate and transform it into project documentation and activities which contribute towards facility construction, operations and maintenance. Failures in the timely and accurate delivery of component information cause delays and uncertainty in the performance of tasks which , in turn, result in poor component selection, incorrect specifications, time delays and re-work, increased change orders, etc. These coordination problems increase the transaction costs between component vendors and customers, and between the other parties who need the information in the course of the facility life-cycle. Thus, improved methods for accessing and using component information can change work processes for manipulating it, and can have a significant impact on the cost, time and quality of facilities.

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[3]A component is defined as a simple (single part) or complex (assembled part) item that is normally manufactured and sold by a vendor and becomes incorporated into the facility. The term "component model" is used to differentiate this information model from "product model" which is used to model the facility itself. The terms "part" and "component" are used interchangeably, though we prefer the latter because it includes complex assemblies of simple parts. In a process plant, the components consist of such items as pipes, valves, pumps, fittings, etc. Clearly, there is a strong overlap in the technologies used for modeling components and products, and there are times when this differentiation is not appropriate. The business issues for vendors (who sell components) and E/C contractors (who design and build plants) are, however, significantly different. This, and the need to identify the special information modeling issues for components, requires that a distinction be drawn between component and product models.

The business problem outlined above is summarized by the following points:

- *Component vendor knowledge often drives final component specification, installation and maintenance procedures*
- *Non value-added effort is required to access, interpret, validate and transform vendor information into project documentation*
- *On complex projects with many participants (the normal case), this effort increases the transaction costs of data exchange*
- *We can use new technologies to improve the timeliness, quality and interoperability of component information throughout the facility life-cycle*

3 RESEARCH OBJECTIVES

The purpose of this research is to understand the problem described above for the process industry. To do this, we study the business issues of component information exchange and the life-cycle information requirements for the components which are installed in process plant facilities. A second goal of this research is to prototype a component information model and software application which addresses the business problem for component selection in an intelligent CAD system.

To understand the requirements we have reviewed the current initiatives in the process plant industry to develop STandards for the Exchange of Product Model Data (STEP) and have performed an information requirements study with participants involved in the exchange of component information for process plants. The investigation of component information requirements, focuses on a representative test case for one component type, <u>the control valve</u>.

From the findings for control valves, we identify the key requirements for business and technical processes which require component information during design and engineering, equipment procurement and construction, and operations and maintenance. We categorize these process requirements according to the form, function and behavior modeling methodology [Kunz, 1988], [Clayton, Fischer, Kunz, Fruchter, 1995]. To date, the ISO/STEP Standards development initiatives for the process industries focus primarily on modeling the requirements for facility design and procurement. Primarily, these standards support only component form and function characteristics.

Using the form, function and behavior approach we are developing a component information model which supports the life-cycle requirements for our test case. This model is being incorporated into a prototype valve sizing and material selection system that works within an intelligent CAD environment. We hope to demonstrate the business case and value-added benefit of representing behavior in addition to form and function in component information models. Such models can reduce or eliminate the time required to search for component information and specify components for a project.

We feel that information models which explicitly represent component behavior are key to the development of software applications which can provide design decision support and improve business process. We plan to test this hypothesis in future research.

4 INFORMATION REQUIREMENTS STUDY

The information requirements study consists of;

- A literature review of the ongoing work in the standardization of parts library data that is occurring in the ISO TC184/SC4, the UN EDIFACT, CIAG and elsewhere. Particular focus was placed on understanding the status and development efforts for the process plant STEP standards and ISO 13584, Standard Part Libraries.

  Considerable efforts are underway by process industry consortia in the United States (PlantSTEP, PDXI, CIAG) and Internationally (PISTEP, SPI-NL, CAESAR-POSC) to define STEP standards. Currently these organizations are collaborating to develop two STEP Application Protocols (AP221 process functional representation, AP227 spatial configuration of plant systems), and a third AP that covers process engineering data has recently been approved for development. The review of the ISO draft standard documents also covered related topics and organizations such as CALS, EPISTLE and CIMIS.[4]

- An investigation of component library architecture's and information delivery strategies that are proposed and/or under development commercially for distributed network environments such as the World Wide Web on the Internet. Such efforts include PartNet [Hadad, 1994] and "A Smart Catalog and Brokering Architecture for Electronic Commerce" [Keller, Genesereth, Singh, Syed, 1994].

- Interviews with representative participants involved in component information exchange. This portion of the study included;
  - A sample survey of component electronic information publication services.
  - An examination of the business challenges and concerns for the participants in component information exchange.
  - A detailed review of the information requirements for control valves from the perspective of the participants who use this information. We describe this part of the study in section 4.4 below.

4.1 Construction Component Information Services

We interviewed two information providers, Autodesk, Inc. and Information Handling Services® (IHS), and we searched the World Wide Web (WWW) for on-line services. The following points highlight the benefits and drawbacks of these services:

Information Source	Benefits / Drawbacks
CD ROM	
• IHS	• 18,000 mfrs. / 63,000 catalogs. Most are scanned images. – No Structured Data except for electronic parts – Search able by Keyword • Improves search time, but no value added for user work processes (IHS is working on ways to integrate their product data into work processes) • Outdated information usage paradigm (bit maps of paper information cannot be understood by the computer)

[4] See Appendix A for list of organizations

• Autodesk	• AutoCAD serves as a productivity tool • ME parts search able by component attributes • .DWG format drawings available with component ID and spec. attributes • Value added limited to graphics and some product data. • Parametric generation of CAD drawings in future version • Looking at on-line, but think market is not ready yet
On-Line	
• AEC Info. Center • Build.com • Others[5]	• Structured documents, text, graphics • Coverage; currently very low, but changing fast • Integration with end-user work processes; low cost to access information • Interactivity; Medium. Users can control search, but can not do much with the acquired information • Visibility; Low, Web sites can be difficult to find
Future	
• Component Catalogs / • Libraries with...	• Interoperable objects with behaviors (foundation classes supported by industry and/or ISO standards)

Table 1. Construction Component Information Services

4.2 Business Concerns

Information Issues

Through the interviews we identified the business issues for the participants involved in information exchange about components. The following table relates the issues to participants.

	Participants			
Business / Information Issues	**Vendor**	**Information Integrator**	**Engineer/ Contractor**	**Facility Owner**
Component Data Standards				
Nomenclature	X	X	X	X
Semantics	X	X	X	X
Interoperability	X	X	X	X
Cost of Modeling	X	X	X	X
Security				
Proprietary Info.	X	X	X	X
Financial Transactions	X	X	X	X
Data Longevity	X		X	X
Time to Market	X		X	X
Cost of Marketing	X			
Improved Maintenance	X			X
Remain closer to client over facility life-cycle	X			X

Table 2. Business Information Issues

[5] See the WWW home page for this project, URL: www-leland.stanford.edu/~jaa/ressum.html

4.3 Business Barriers

The business barriers to effective component information exchange include:

- Industry Fragmentation; No Standards for data exchange
- Long term benefits of detailed information modeling conflict with short term business goals
- Differing levels of automation;
  - Low automation for some processes/companies
  - Many companies are not on-line
  - Lack of interoperability
- Belief that competitive advantage lies in proprietary knowledge
  - Engineer/Contractor: technical expertise and cost estimation knowledge
  - Vendor: technical marketing
- CAD systems do not meet user requirements
- Organizational inertia
  - Embedded culture resistant to change
  - Risk aversion
  - Lack of understanding and training in new business processes
  - Cost of converting to new business procedures and standards

5 LIFE-CYCLE OF A CONTROL VALVE - A CASE EXAMPLE

5.1 Objective

We investigated what detailed information would be necessary to support the business requirements described above for a component used in a process plant ; i.e. reduce the transaction costs associated with long cycle times, marketing costs, contract governance, maintenance and operation costs.

5.2 Coverage

The study focused on the information requirements for control valves. Information was gathered through interviews that were conducted with industry professionals who take part in component information exchange, and through ongoing dialogue and email exchange with individuals who were involved in the standards development initiatives described above.

The interviews were conducted with twenty-two individuals representing nine different companies. They were conducted on an informal basis, guided by a question list developed for each company type. The purpose was to gain an overall picture of the participants, the relevant work processes, the information that is required for each process, how each participant uses the information, what media they use to exchange the information, and what software tools are used to process it. The responses were recorded in note form during each interview. The types of companies which were interviewed includes;

- 3 engineering/contracting firms who perform process plant work
- 2 valve manufacturer/vendors
- 2 component information providers
- 1 Facility owner
- 1 EDI Vendor

5.3 The Life-cycle Phases that were included in the Study Relative to Information Requirements for Valves

The highlighted nodes in the IDEF0 diagram below show the phases of the facility life-cycle that were studied:

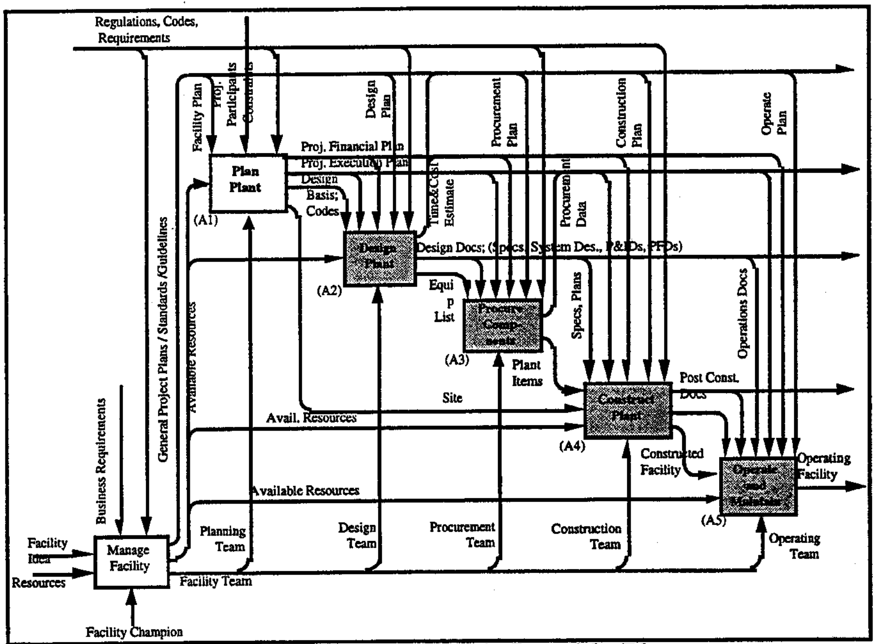

Figure 1. IDEF0 Node 0: Provide Plant

Within these phases we focused on the following activities:

- Design Plant
  - Conceptual process design
  - Conceptual engineering design
  - Detailed process design
    - Valve sizing
  - Detailed engineering design
    - Valve selection
- Procure Components
- Valve purchase, shipment and delivery
- Construct Plant: Valve installation
- Operate and maintain plant

5.4 Analysis Method

We developed a hypothetical project scenario in which we identified the component information that should be represented for valve components during the various work processes that occur within each phase of the process plant life-cycle. To frame the work processes and information issues relative to valves within each life-cycle phase, we used the IDEF0 process modeling technique[6]. A draft version of the report describing this study is complete. Some of the report findings are highlighted below.

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[6]These diagrams are derived from, and extend the ISO 10303-227 Application Activity Model diagrams and the Integrated Building Process Model developed by Sanvido) [Sanvido et al, 1994]. The diagram provided in Figure 1., Node 0: Provide Plant, is the top level diagram. In the study, the relevant phases are decomposed into lower level diagrams and activities in which component information is exchanged or used.

5.5 Case Study Findings

Business Issues

- Current business processes carry high transaction costs; e.g. Valve specification can be redundant. In traditional work processes it is repeated three times: after detailed design, at vendor review of the Request For Bids and during valve specification modifications after vendor selection.

- Current valve specification methods require high marketing costs for component vendors.

- Valve specification is labor and knowledge intensive (for owner, vendor and E/C contractor)

Life-cycle Information Requirements

Life-cycle information requirements necessitate component information models that describe behavior in addition to form and function information. Behavior for valves varies according to the thermodynamic behavior of the process fluid and pipe system. A valve should be sized to consume "whatever pressure drop is available to maintain a system at a set point" [Chevron, pg. 900-4]. Looking at the diagram on the left below, one observes that at high flows, a valve does not have to consume as much pressure to control the flow. The valve must operate satisfactorily across a dynamic range of system behaviors defined by pressure head, stream velocity, temperature and fluid composition. The valve functions which are evaluated as a function of the system characteristics include:

- Valve capacity - Coefficient of Flow
- Cavitation, Flashing

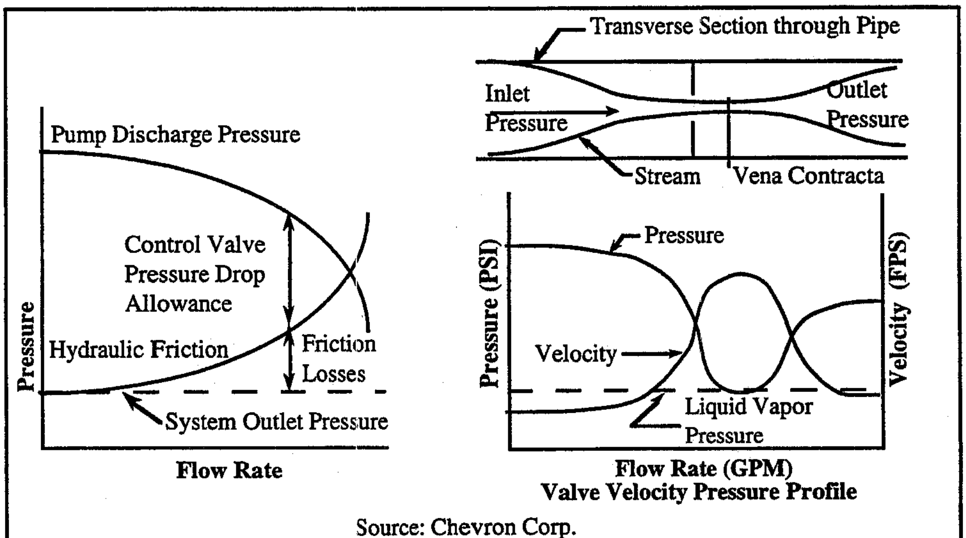

Figure 2. Valve Performance Constraints [Chevron Corp., 1993]

Because the valve causes a pressure drop in the system relative to the stream velocity, one must also calculate whether the pressure drop will fall below the vapor pressure of the stream for its operating range of temperatures and pressures. If this occurs, cavitation or flashing may occur. Cavitation is a condition where the stream changes state from liquid to vapor in the valve (see diagram on the right above). When the system pressure recovers after exiting the valve the vapor bubbles collapse, causing cavitation. If the valve outlet pressure stays below the stream vapor pressure, flashing will occur. Either of these conditions will cause damage to the valve and pipe.

Valve behavior will also vary according to the trim materials selected for a required service condition. Service Conditions, and consequently trim configurations, are defined by factors such as:

- Control Requirements;
  - Quick Opening
  - Linear Opening
  - Equal Percent Opening
- Regulations;
  - Quality and Reliability
  - Fire
- Environmental constraints;
  - Sound
  - Fugitive emissions

In addition, valve behavior degrades according to the length of time in service. The diagram on the left below shows the ideal, or inherent, flow characteristics which result from each type of trim;

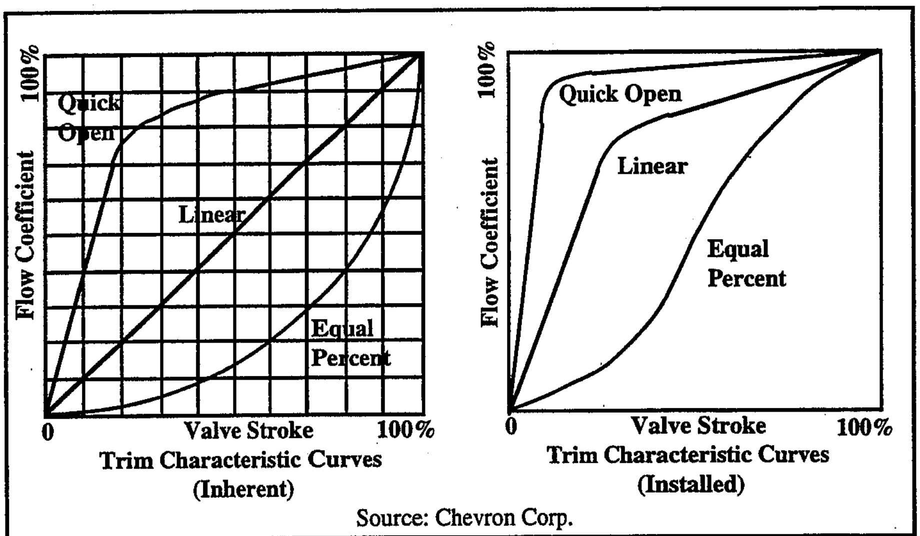

Figure 3. Valve Control Characteristics [Chevron Corp., 1993]

In reality, friction losses in the system due to rust accumulation produce different behaviors once the valve has been installed and the system is up and running. The diagram on the right shows the installed characteristics. With time, equal percent trim behaves more like linear trim. Linear trim, in turn, behaves more like quick opening trim. Depending upon the "burn in" time for the system and the relative cost of different trim characteristics, it may be advantageous to select equal percent trim for a service condition which requires linear flow control. The change in flow control performance due to trim deterioration demonstrates that the information requirements for selecting materials include the representation of the changes in the material's behavior across time as well as inherent behaviors at a given time.

Implications for an Information Model which satisfies life-cycle requirements

The factors described above provide some insight into the life-cycle requirements for a component information model.

- An information model that satisfies the life-cycle requirements necessitates an explicit representation of component parts, to model the deterioration of performance and maintain a detailed maintenance history for regulatory requirements.

- The information model must be able to represent the range of purposes for its use (functions) and the engineering knowledge which describes them.

- The model must be capable of representing component behavior in response to a range of functional requirements and business rules. The behavioral model should also be able to represent performance changes due to component degradation. Such changes can affect the initial component selection strategy.

Including behavior in the component model is necessary for providing decision support capability. The definition for a component behavior includes both its predicted performance based upon its form and material composition, and how it performs within a given set of constraints conditions. For components, the constraints include the functional requirements and business rules for material selection. The inclusion of behavior in the model makes it possible to reason about the state conditions of the component and perform design evaluation. Clayton defines evaluation as "...the prediction of the behaviors of the forms and the assessment of behaviors with respect to functions." [Clayton, Fischer, Kunz, Fruchter, 1995] The capability for evaluation enables software functionality for automated design decision support, which in turn can enable business process change.

Another dimension of behavior to consider is that the functional requirements and business rules which determine material selection change as a design project develops. One reason for the redundancy in the control valve specification process is that the business and functional requirements change as the project takes on definition. Another challenge for developing information models which provide design decision support will be to build a capability for dynamically representing changes in the assumptions about business rules and functional requirements which affect component material selection. Such a capability will be central to any model which seeks to capture the essence of design process in which knowledge about the design increases iteratively as the design definition develops.

Detailed information modeling is costly. Nonetheless, we feel that component information objects which encapsulate form, function, and predicted and assessed behavior, will be key to providing the value-added benefit of providing design decision support and improving business process.

The Current ISO/STEP process plant component modeling efforts do not yet support the behavioral requirements described above. These models do not include the engineering knowledge necessary to support product selection. The STEP models focus on "snap shot" exchange of design documents rather than information sharing between design objects. This is an important conclusion of this study, and hopefully one where our modeling efforts can make a positive contribution to STEP.

6 CURRENT STATUS; AN INFORMATION MODEL PROTOTYPE

In addition to the "Life-Cycle of a Valve" report we are developing a prototype implementation of a valve information model which will fulfill several of the requirements stated above. We are developing this model using the Symbolic Modeling Extension-Kappa prototype environment described by Clayton [Clayton, Fischer, Kunz, Fruchter, 1995]. This implementation enables us to investigate the modeling issues and test whether the model can provide value added benefit by evaluating its performance for a test case.

In a report on the increased effectiveness of implementing partnership agreements with valve manufacturer's[7] one CIFE member notes that on complex petro-chemical projects, the actual man-hours per control valve (valve sizing, selection and procurement) was reduced from 8 to 2 hours. Most of the time savings were realized by turning over the data sheet specification process to the supplier. The purpose of our prototype is to investigate whether it is possible further reduce (by an order of magnitude) these tasks by encapsulating valve data and engineering knowledge into objects which are incorporated directly into the design.

In our implementation, we develop the concept of a valve sizing "interpretation" which instanciates a P&ID sub-system comprised of two or more pipe segments, a stream, and a valve object. For the present, these objects are sub-classed under an abstract class named Pipe_System_Item (At a future date this class definition will be changed to conform with the appropriate STEP models). For a given P&ID diagram, an interpretation would be constructed for each control valve in the design.

Each of the objects described above is related by association to abstract form, function and behavior (FFB) objects that explicitly represent FFB properties for pipe segments, streams and valves. At present, the FFB objects are sub-classed under an abstract class named Generic_FFB. In the future, we will investigate an FFB ontology of abstract classes. The primary FFB objects in this model include the following:

- Form - Valve body type, size, and material; pipe diameter and material; stream composition.
- Function - Required valve capacity; stream purpose, pipe segment purpose.
- Behavior - N valve behaviors representing performance dependent upon thermodynamic system characteristics; stream behaviors dependent upon composition, temperature and pressure.

[7]Many firms are instituting new procurement procedures, in the form of vendor partnership agreements, to reduce the non-value added effort in component specification and procurement. Such agreements have been shown to cut valve selection and procurement costs by half. These agreements redesign the procurement cycle by shifting responsibility for valve specification and selection onto the vendor. However, these work process changes have not yet extended to new technologies for interoperable exchange of electronic design documents.

The model will provide decision support for the following work processes:

- Valve Sizing
- Valve Selection for a specified service condition

We are beginning with a simple test case, which once validated, will be substituted with one that conforms to a usage scenario developed for ISO WD 10303-227. The current test case consists of the following scenario:

- Size a valve
- Context: River water system that provides cooling for a process stream:
- Process fluid: water
- Functional requirements:
  - 8" schedule 30 pipe
  - Flow Rate = 1600 gpm
  - Inlet pressure = 42.6 psia, Outlet pressure = 34.7 psi

The metric for this exercise will be to reduce the time required to fully specify a valve from the order of hours to minutes by encapsulating component selection rationale, business and engineering constraints into a design object.

7 FUTURE WORK

The plans for future work include:

- Extend the model for valve selection;
  - Incorporate Business rules for service conditions and maintenance requirements to select valve trim and other accessories.
- Contribute to STEP Standards

In the long term, (beyond the scope of the current project) we would like to:

- Incorporate a Library reference structure
- Develop modeling concepts to;
  - represent the design process and the development of component knowledge from initial to detailed states
  - represent changing assumptions about requirements based upon business rules and service conditions
- Integrate the object model into EDI procurement standards so that this important business activity can be based on new modeling approaches

8 EXPECTED CONTRIBUTIONS

The contributions that we anticipate making from this project include;

- Formulation of a clear business case for developing component information models that support the life-cycle requirements for process plant facilities.
- New insight into the process plant life-cycle information requirements which information models for components should support.
- A prototype implementation of an information model which demonstrates its benefits in representing component behavior and providing decision support in an intelligent CAD system.
- Useful input into the ISO 10303 Application Protocol and ISO 13584 Standard Parts Library development efforts.

Acknowledgments

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References

[Chevron corp. 1993]	Chevron Corp. Instrumentation and Control Manual Section 900, Control Valves June, 1993
[Clayton, Fischer, Kunz, Fruchter, 1995]	[Clayton, Mark J. S.M. ASCE; Fischer, Martin A.M. ASCE; Kunz, John C.; Fruchter, Renate M. ASCE ,1995] Behavior Follows Form Follows Function: A theory of Design Evaluation Second ASCE Congress on Computing in Civil Engineering, Atlanta, Georgia 1995
[Haddad, 1994]	Haddad, Rami Laitif Presentation and Representation of Design Data in PARTNET, unpublished Masters Thesis. Dept. ME, University of Utah. (August, 1994)
[Keller, Genesereth, Singh, Syed, 1994]	Keller, Arthur; Genesereth, Michael R.; Singh, Narinder P.; Syed, Mustafa A., A Smart Catalog and Brokering Architecture for Electronic Commerce Stanford Center for Information Technology (CIT), Stanford. CA A short paper available on-line at; http://logic.stanford.edu/cit/cnte.papers.html
[Kunz, 1988]	Kunz, John C. Model Based Reasoning in CIM Intellicorp 1988, Mountain View, California 94040
[Sanvido et al, 1994]	Sanvido, Victor et al. An Integrated Building Process Model Report of Research Sponsored by the National Science Foundation Grant No. DMC-8717485 Technical Report No. 1 Copyright January 1990 Computer Integrated Constuction (CIC)

Appendix A

CAESAR*	The ***CAESAR*** Standard Parts library pilot project is one of several projects in the CAESAR Offshore research program. CAESAR Offshore is a European consortium organized to develop products and methodologies which will enable European oil and natural gas industries to use digital information effectively in offshore development and operation, and to redesign work processes and organization around new information and communication technologies. Participants in CAESAR include "Statoil, Norsk Hydro, Saga Petroleum, Aker Dvaerner, Det Norske Veritas, The Norwegian Institute of Technology (NTH), The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF), and The Federation of Norwegian Engineering Industries (TBL).
CALS	***Computer Aided Logistic and Support Initiative*** Begun initially by the Department of Defense in the 1980's, CALS activities have extended from the defense contracting industries to manufacturing industry in general as companies realize the improved efficiencies through data standardization.
CIAG	***Construction Industry Action Group*** An action group for the Construction Industry Institute (CII/CIAG)
CIMIS	***Common Industry Material Identification Standards*** CIMIS is supported by the American Petroleum Institute/Petroleum Industry Data Exchange (API/PIDX), CII/CIAG, and the Pipes Valves and Fittings roundtable (PVF).
EDIFACT	***United Nations/Electronic Data Interchange For Administration, Commerce and Transport.***
ISO/TC184/ SC4	***International Standards Organization/Technical Committee 184/Sub Committee 4***
EPISTLE	**European Strategic Program for Research and Development in Information Technology**
PISTEP*	**Process Industries STEP Consortium** A UK based consortium of large plant owners and engineering contractors dedicated to the development of STEP standards.
PlantSTEP*	**PlantSTEP** A US based consortium of process plant owners and engineering contractors dedicated to the development of STEP standards.
SPI-NL*	**Cooperative Association for the Process Industry in the Netherlands** A Dutch based consortium of large plant owners and engineering contractors whose charter is to promote the development of STEP standards.

*These Consortia are working in close cooperation with one another through the EPISTLE framework.