NISTIR 6221

A Brief History of Early Product Data Exchange Standards

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U.S. DEPARTMENT OF COMMERCE
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Raymond G. Kammer, Director

ABSTRACT

The following paper traces the history of product data exchange standards from the physical model through electronic representations such as IGES. This paper provides an understanding of the early efforts leading to ISO 10303—STandard for the Exchange of Product model data (STEP), but does not cover STEP's development.

1. INTRODUCTION

> "Before the dawn of the industrial revolution, engineering work was defined by a physical model of a product to be reproduced. For example, a worker manufacturing a rifle barrel would ensure that the dimensions of the barrel corresponded to a model barrel by using calipers to transfer measurements from one to the other. This method reinforced the concept of workers manufacturing specific product types rather than generic components of larger products.
>
> In 1801, Gaspard Monge wrote "La Geometrie Descriptive" as the first treatise on modern engineering drawings. This included the theory of projecting views of an object onto three planes and the addition of size specifications to the shape descriptions. With the mechanical drawing, an objective standard of performance for workmanship was possible and thus the model could be eliminated. The drawing enabled the practice of designing a product with interchangeable parts to be created. Operations could then be performed using contractors that could manufacture different pieces to be assembled. This capability led to the fragmentation of the manufacturing process that exists to this day.
>
> The mechanical drawing concept has lasted for almost 200 years. As described above, the manufacturing process for developing quality products was interwoven with the method for describing the products. The drawing became the output of the design process and the input into the manufacturing process. Drawings were converted into process plans, which were converted into programs or procedures for the manufacturing operations. Thus, every process has its own view of the product data. These dissimilar views have made it difficult to feed back knowledge about different processes to the designer. In today's industrial enterprises, the lifecycle processes for a product are no longer all performed by the same group of people. In fact, the processes are distributed through a network of factories.
>
> As we move into the twenty-first century, new manufacturing technologies are needed to improve productivity and competitiveness. In this information and computer age, companies exchange and share information across the country. This capability is needed for manufacturing the complex products such as automobiles, airplanes, ships, and buildings that are produced today. There is a special consideration for accelerating this information exchange process since the existing products and technologies are often replaced before their useful life has expired as manufacturers compete in the marketplace. To meet production deadlines, computer-aided design tools are used to move products from concept, through design, prototype, manufacture, test and, ultimately the support that is required by the customer."[1]

Representing product data has evolved slowly over these same 200 years (see Figure1). Before the year eighteen hundred, a tangible physical model of a product defined product descriptions. The invention of engineering drawings in the early 1800's led to more precise product descriptions. This increased productivity many fold over using a physical model to define a product.

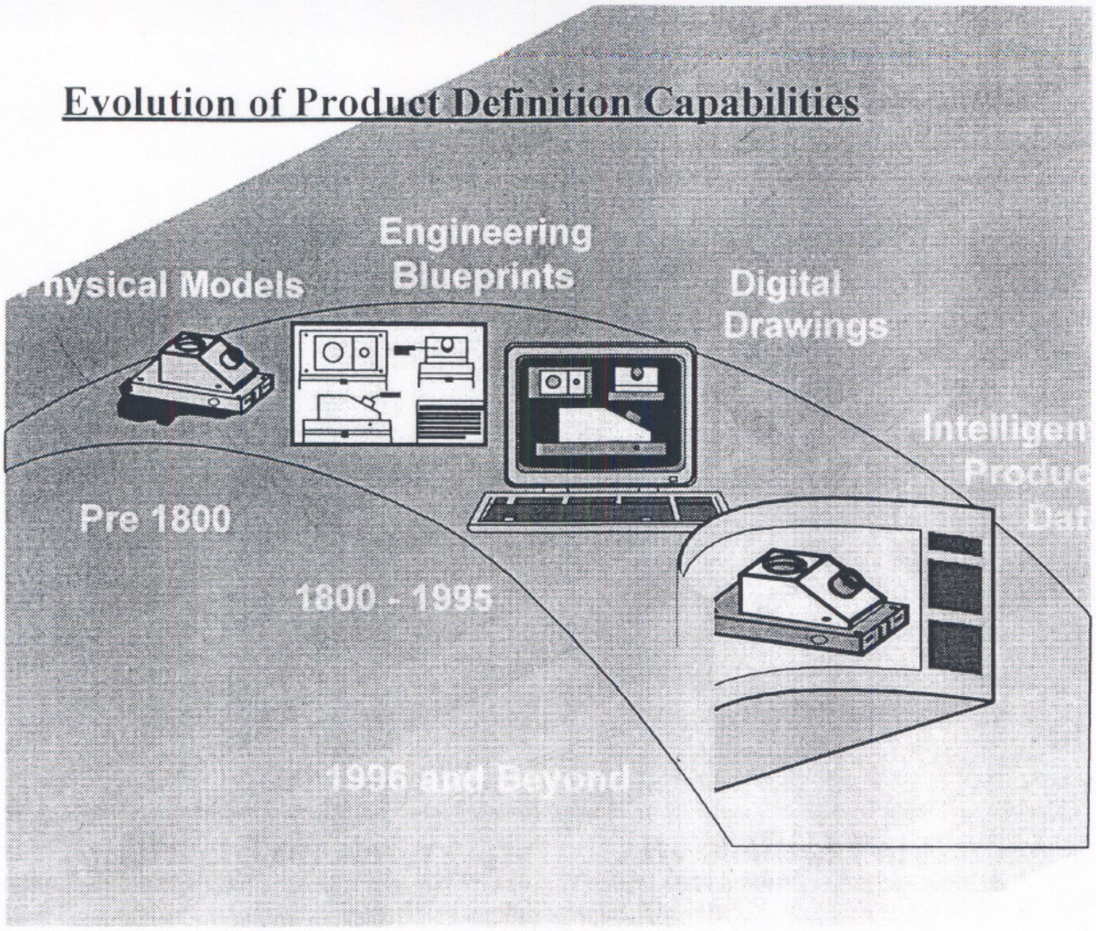
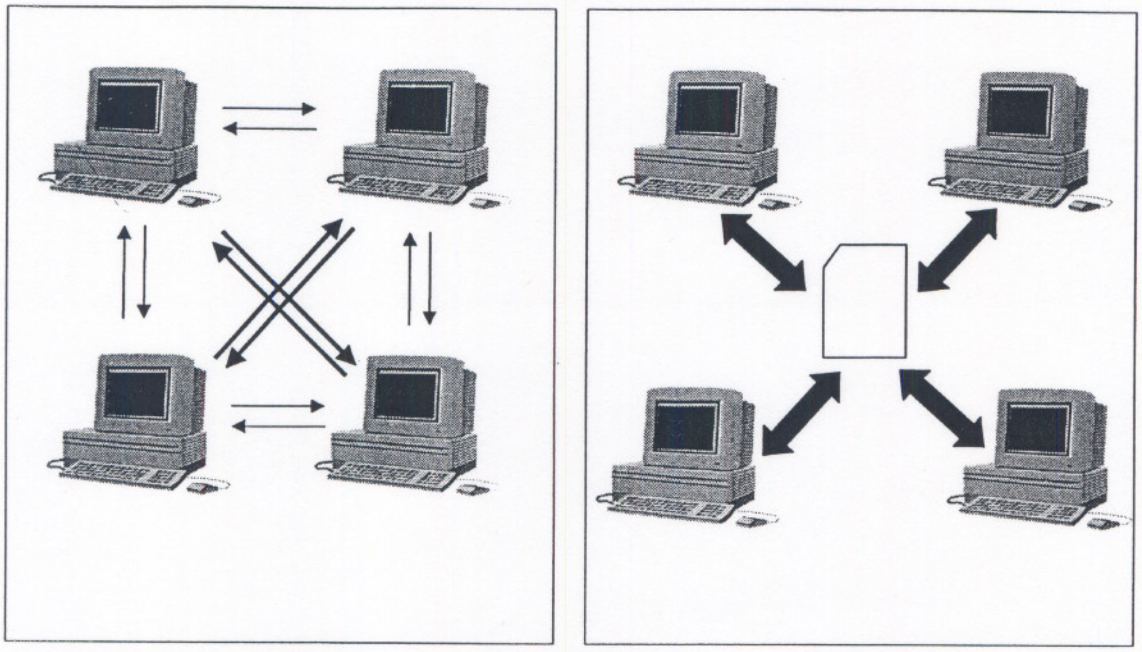


Figure 1. Evolution of Product Definition Capabilities, PDES, Inc.

Drawings created within Computer-Aided Design (CAD) tools represented a tremendous productivity gain over paper drawings, such as ease to revise and archive. CAD tools also opened new opportunities, such as enabling manufacturing instructions to be automatically derived and executed directly from the drawing. Nevertheless, as computer design and manufacturing tools proliferate, so do the formats each tool uses to capture and store product data. While paper drawings can be marked up by anyone with a pencil, a product model that can not be interpreted by the needed CAD tool is useless. For organizations to share designs that must be interpretable across various CAD and Computer-Aided Manufacturing (CAM) tools, they must be formatted in a manner that the tools can recognize. This requirement is becoming increasingly important in an age where large manufacturers often form joint ventures to address a business opportunity, and where partners in a supply chain are being called upon to deliver an increasingly complex array of services. Most companies find it difficult to enforce the use of a common set of CAD/CAM tools within their organization, much less across (multiple) supply chains and among joint venture partners. This need for an efficient means for multiple applications to share engineering data has driven the development of a standard for a neutral intermediate format. Such an approach allows a manufacturer to avoid developing and maintaining several system-specific interfaces, as shown in Figure 2, and enables applications and equipment to be driven directly from a shared file.

Efficiency of a Neutral Format for Data Exchange



... By Direct Translators **... By Neutral Format**

Figure 2. Source: Department of Trade and Industry, "Product Data Exchange, An Introductory Guide," Finallay Publications, UK

2. EARLY STANDARDS DEVELOPMENT EFFORTS

The tools and strategies for creating a common information exchange language emerged from a variety of industry, academic, and government efforts—both national and abroad. For example, in the 1970's the X3/SPARC Committee of the American National Standards Institute (ANSI) contributed the notion that data should be described in a manner that was independent from particular uses or computer technologies. This committee proposed a three-schema methodology with which one basic conceptual information model could be realized in a variety of computer technologies, and presented to users through a variety of filters. These different views of the same information were called conceptual, internal, and external views, as shown in Figure 3 [2][3][4].

ANSI/SPARC Three-Layer Architecture

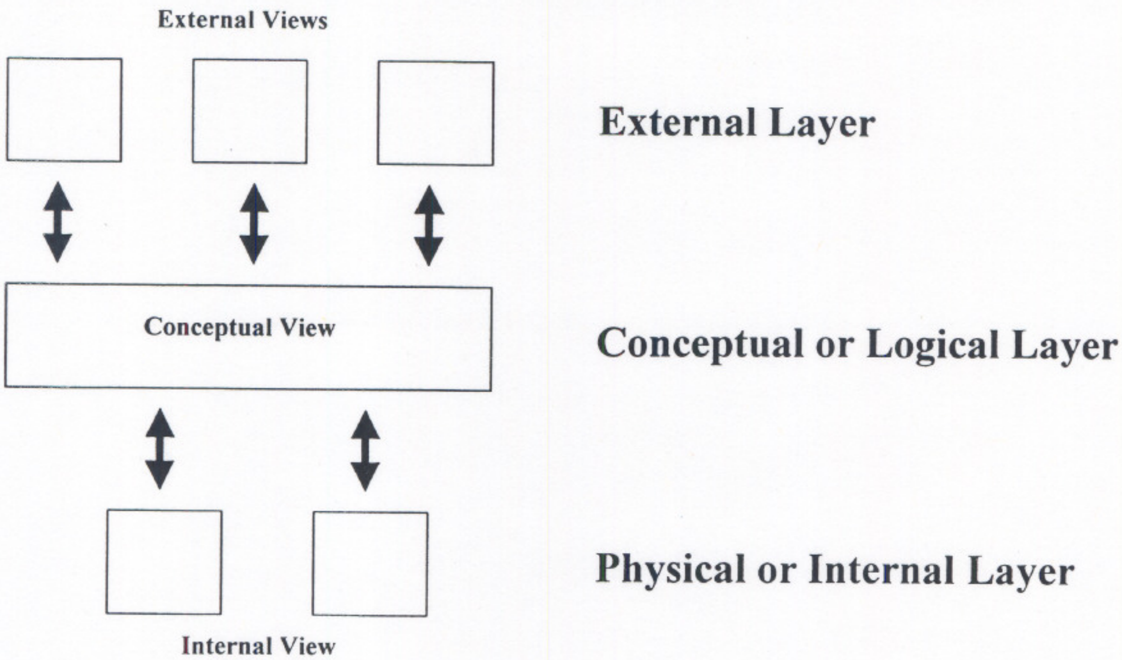


Figure 3. Adapted from Fowler, Julian, "STEP for Data Management Exchange and Sharing," Technology Appraisals Ltd., Great Britain, 1995.

The U.S. Air Force built upon the ANSI/X3/SPARC methodology by developing formal methods for information modeling, as a result of their Integrated Computer Aided Manufacturing (ICAM) program. The intent of ICAM was to develop new manufacturing automation technologies, which could lower the overall cost of procurements. It was determined that new systems engineering methodologies were needed for developing new technologies, which implied new methods of defining requirements. This work resulted in a suite of formal methodologies: IDEF0 for modeling activities; IDEF1 (later extended to IDEF1X) for modeling information; and IDEF2 for modeling system dynamics [5]. ICAM then awarded a series of specific contracts that required the use of these new systems engineering methodologies. The Integrated Programs for Aerospace-Vehicle Design (IPAD), for example, had a geometry focus, and is credited as being the first to make use of information modeling for systems integration [6].

ICAM, and its subsequent contracts including the Product Definition Data Interface (PDDI) and Geometric Modeling Application (GMAP) programs, contributed much to the tools and methodologies later applied in subsequent standards. Other efforts contributed to the formal description of the information needed to be shared among CAD systems. The Computer-Aided Manufacturing - International Inc. (CAM-I) organization, through the Geometric Modeling Project that it began in the early 1970's, contributed significantly to the formal description of Boundary Representation (B-REP) data. The result of the CAM-I funded work, which was a mathematical representation of standard geometry and topology, was considered ahead of its time and clearly captured more information than the typical CAD systems of the day could interpret. It was submitted to ANSI committee Y14.26 (Computer Aided Preparation of Product Definition Data) for standardization. The CAM-I specification did not contain an exchange mechanism, but a foundational description of that data which could be exchanged [7].

2.1 THE BIRTH OF IGES [8][9]

In 1979 events took place that catalyzed the CAD vendor and user community to create the first national standard for CAD data exchange. Mechanical CAD systems were less than ten years old, and there were only a handful of products with any significant market penetration. Even at this early stage, users were overwhelmed by the inability to share data among these tools and with their own internally-developed databases. Frustration was evident at a fateful two-day Society of Manufacturing Engineers (SME) meeting in the Fall of 1979. On the first day, an attendee from General Electric (GE) challenged a panel of CAD vendors, that included ComputerVision, Applicon and Gerber, to work together to enable a common neutral exchange mechanism. While this need was intuitive from a user perspective, this was a very threatening proposition to the CAD vendors—who feared that publicly sharing the structures of their databases would be tantamount to giving away their competitive advantage. It would have been easy to gloss over the challenge; after all, the major vendors all had at least token representation on the ANSI committee responsible for CAD standards. Instead, the ComputerVision representative responded with a challenge of his own: If Boeing and General Electric (and perhaps others) would contribute the CAD translators they had already developed, the vendors would share their database structures.

What led to this offer was a fortunate blend of business motivation and private agendas. It just so happened that the evening before the CAD panel, a CAD vendor representative was busily recruiting employees for his (unannounced) new robotics company. In forming this company, he gained the user's perspective: his product was going to need to have access to CAD data! If he could set the wheels in motion for the CAD vendors to make public their database structures, his new company would have a better chance at success; however, an exchange standard was also in the CAD vendors' best interest. The CAD vendors tried to differentiate themselves based on loyalty to their customers, that also had the negative effect of dividing the end users into camps. There were large Navy contracts looming on the horizon, and no vendor wanted to look unresponsive to customer requirements.

In the evening after the panel, several interested parties gathered in a smoke-filled room and asked themselves if a common translator was really possible. The room had the right combination of people at the right time. This included an Air Force ICAM representative willing to fund such an effort and a National Bureau of Standards (NBS)[1] representative who, after a call to his boss at home for a sleepy approval, was willing to champion it. This whole initiative was thus initiated with a $50,000 contract that established the effort's initial structure and requirements [10]:

- An NBS representative was placed in the lead[2];
- Two initial IGES committees were formed: the Steering Committee to manage the effort and a Working Committee to perform technical work;
- A draft was to be delivered within three months.

With the fundamentals decided, conversation turned to a name for this new translation project. The group nixed the suggestion "Universal Translator" to avoid offending those within ANSI, who might have interpreted the project as a way to displace the years of effort already put towards a Y14.26 standard. A minimalist approach was suggested:

I	Interim, to suggest that it would not replace ANSI's work;
G	Graphics, not geometry, to acknowledge that academics may come up with superior mathematical descriptions;
E	Exchange, to suggest that it would *not* dictate how vendors must implement their internal database; and
S	Specification, not to be as imposing as a standard.

The panel reported on the second day, and the wheels were set in motion to create an "IGES." Once the panel admitted that a common translation mechanism was possible, it was impossible to stop the momentum of the customers' enthusiasm and expectations. Applicon and ComputerVision agreed to open up their internal databases, GE offered its neutral database, and Boeing offered the structure of its Computer Integrated Information Network (CIIN) database. Both GE and Boeing contributed their existing translators. A core team was formed that included representatives from NBS, Boeing, and GE. Team members had worked closely with each of the vendors on internal integration projects. This prior experience built the expertise and trust needed to craft a solution in a very short time, and neither vendor felt it gave an unfair advantage to the other.

Soon after, an open meeting was held at the National Academy of Sciences on October 10, 1979. Approximately 200 people attended to herald the birth of IGES. There was an atmosphere of extraordinary excitement, although not everyone was supportive. In addition, although it was hotly debated, the name of this project was eventually accepted with the minor change from "Interim" Graphics Exchange Specification to "Initial" Graphics Exchange Specification.

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[1] Department of Commerce's National Bureau of Standards was later renamed the National Institute of Standards and Technology (NIST).

[2] Roger Nagel of NBS, Walt Braithwaite of Boeing and Philip Kennicott of GE formed the initial IGES team.

After two critical reviews, the IGES team released its first draft in January 1980, containing geometry, graphical data, and annotations. IGES was submitted to the ANSI Y14.26[3] committee for standardization, which forced the committee to try to reconcile the very different views embodied by the IGES work and the work funded by CAM-I on boundary representation description. When version one of IGES was standardized (Y14.26M-1981[4]), the work funded by CAM-I was attached but unintegrated with the remainder of the standard. This work was contained in the section entitled "Section 5 - Basic shape description." Future versions of the IGES standard omitted this fifth section.

2.2 PRODUCT DEFINITION DATA INTERFACE (PDDI)

IGES provided a very practical first solution for CAD data exchange, complete with an exchange file format. It was remarkable in the speed with which it was developed, due in part to the relatively limited scope, the small size of the committee working on it, and a commitment to produce a draft within three months. Once it fell under the scrutiny of an ever-broadening community, weaknesses were identified that eventually justified embarking on a new standard that could break tradition with IGES. The Air Force ICAM program again made a significant contribution to the evolution of product data exchange standards, this time through its Product Definition Data Interface (PDDI) contract. The purpose of PDDI was to develop a mechanism to allow the complete exchange *or sharing* of product model data directly among computer applications—without human intervention. PDDI with its geometry focus, developed a set of information models, a modeling language that contributed to EXPRESS [11], an exchange file format that separates the data being exchanged from its definition, and a mechanism for applications to share data.

One of the tasks of this contract involved an evaluation of IGES in the context of its current implementations. This resulted in a thorough report [12] and numerous constructive requests for changes to IGES. This evaluation activity helped the community clearly define IGES's shortcomings:

- Flavorings. IGES contained several ways to capture the same information, which made proper interpretation largely dependent on the particular "flavor" of the pre- and post-processors.
- File size/processing time. IGES was heavily criticized for requiring large files that took hours or even days to parse, given the average computing power available at the time.
- Loss of information during exchange. Information would inevitably be lost when information is passed between two CAD systems with inherently different capabilities.
- Lack of discipline, architecture. There was a perception that IGES was developed without rigorous technical discipline, and that the use of information modeling would be useful.
- Upward compatibility. The need for generations of processors to parse files compliant with earlier versions of IGES thwarted the breadth and rate of change in succeeding versions.
- Automated, rather than improved upon, paper system. IGES was seen as a method to exchange engineering drawings, but not capable of capturing complete product data (including administrative information) to enable more sophisticated automation.

Although PDDI was a research exercise, it contributed understanding, mechanisms, and models to future standards, most notably ISO 10303—Standard for the Exchange of Product Model Data (STEP).

Additional shortcomings were later identified in a paper by Peter Wilson:

- Subsetting. Vendors selected and implemented only portions of the whole of IGES, thus making exchange between two systems impossible without prior agreement on what was to be exchanged.
- Conformance testing. There was no mechanism for testing processors or resolving errors between two processors [13].

2.3 SUBSETS AND APPLICATION PROTOCOLS

The use of formalized subsets of IGES entities offered one approach to improving the quality and predictability of translations. NBS, under sponsorship from the U.S. Department of Defense Computer-Aided Acquisition and Lifecycle Support (CALS) program, led the development of IGES subsets. The U.S. Department of Defense eventually stipulated IGES subsets for various application areas, such as technical illustrations and electrical/electronic applications, within their CALS suite of military standards. Subsets allowed IGES processors to be classified by the functionality that they could support *entirely*, and acted as a predefined written agreement

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[3] ANSI Y14.26 committee name is Digital Representation for Communication of Product Definition Data.

[4] Since revised and republished as ANSI/US PRO/IPO 100.

between a sending and receiving party. The IGES community quickly learned that merely specifying subsets of entities was insufficient—accurate exchange required additional instructions for mapping CAD system data to the specified IGES entities. STEP's concept of application protocols (APs) and Conformance Classes grew from the lessons learned regarding IGES entity subsets and the early work done by NIST for the U.S. Navy on the IGES Architecture, Engineering, and Construction (AEC) application protocol.

The first demonstration IGES AP was the Department of Energy Data Exchange Format (DOEDEF), which was developed by the design and production agencies of the nuclear weapons complex in 1985. The DOEDEF AP specified a subset of IGES entities with instructions on data translation, and a few "user-defined" entities for data specific to weapons systems. Software was developed at Sandia for translating individual CAD IGES data into and out of DOEDEF, and the complete system was demonstrated in March 1986. The first standard IGES AP was the IGES 3D Piping AP, developed in large part through work on the Navy Navy/Industry Digital Data Exchange Standards Committee (NIDDESC) contract.

3. INTERNATIONAL PLAYERS

Several international efforts also contributed to the evolution of data exchange standards.

3.1 AECMA REPORT OF GEOMETRY DATA EXCHANGE STUDY GROUP

In 1977, the European aerospace industry recognized a major problem in exchanging shape representation on collaborative projects. The European Association of Aerospace Industries (AECMA) developed a common exchange format, based on a simple surface type, that allowed the collaborating companies to exchange surface geometry. The format was used on a few occasions, but the advent of more complex surface types, integrated into vendor systems, caused it to fall into disuse [14]. Even so, there was good work done by AECMA. The United Kingdom contributed the AECMA Report of the Geometry Data Exchange Study Group to the International Organization for Standardization (ISO) effort for building an international product model data standard [15].

3.2 FLACHENSCHNITTSTELLE DES VERBANDES DER DEUTSCHEN AUTOMOBILINDUSTRIE (VDA-FS AND VDA-IS)

The Germans standardized Flachenschnittstelle des Verbandes der deutschen Automobilindustrie (VDA-FS), which addressed the exchange of free form surfaces and free form curves needed by the automotive industry. VDA-FS offered a competing exchange file format to that of IGES. The VDA was created in 1982 to increase the efficiency of the design process and usefulness of CAD/CAM systems. The Germans brought VDA-FS to the international table to contribute toward the international product model data standardization effort [16].

The German automotive industry, through VDA-IS (IS-IGES Subset), defined subsets of annotation entities relevant for various applications in automobile manufacturing. These subsets were created so that compliance could be tested. The particular data exchange requirements met by these subsets included: drawing information, two- and three-dimensional geometry, and analytic and free form surfaces [17].

3.3 STANDARD D'ECHANGE ET DE TRANSFERT (SET)

The French Standard d'Echange et de Transfert (SET) project started at Aerospatiale in 1983. Designed to address the difficulties using IGES, the primary industrial drivers of SET were automotive and aerospace industries. The SET standard represents the results of the requirement to exchange data between different CAD/CAM systems, and from the need to archive these data. Version 1.1 of SET was put on the international table to contribute toward the STEP activity. It contained:

- Detailed specifications for the mechanical area,
- Supplementary information about the data structures and concepts employed, and
- Rules and recommendations concerning specifications to ensure coherence in future developments [18].

Association GOSET is an organization established by industry and government in France to support continued development and maintenance of SET. GOSET representatives have also been active contributors to ISO 10303 and STEP conformance testing services [19].

4. THE PDES INITIATION EFFORT

By 1984, many of these international efforts had produced enough results to be compared, and an international community was preparing to form in hopes of creating a common solution to CAD data exchange. The drivers for a common international standard included:

- Global commerce and data exchange;
- Increasingly complex products;
- Multi-use software, e.g., design or engineering systems that apply to multiple industries and applications;
- Reliance on suppliers at all phases of product development;
- Need for lifecycle support.

Many felt that IGES could not adequately respond to these pressures.

In May of 1984, a late night meeting of the IGES Organization Edit Committee was held. The outcome: the Boeing representative was tasked to write a paper on what the next generation of IGES might look like without the constraint of providing upward compatibility for IGES processors. This informal request was in response to pressures from the PDDI results and European efforts. The first Product Data Exchange Specification (PDES) report was issued in July of 1984, and was followed by a second report in November of 1984. These reports laid the groundwork for the PDES Initiation Effort, which, similar to PDDI, was considered a theoretical exercise at building a standard based on a broader automation goal and the discipline of information modeling. The PDES Initiation Effort used a simple machined part as a product emulator, and focused on both the logical information being captured and the "physical" mechanisms of data exchange. Those involved originally assumed that this next-generation standard would be IGES Version 3. Instead, the work spawned a separate U.S. national effort known as PDES [20]. PDES was eventually folded into the international effort led by ISO TC184/SC4 responsible for developing and standardizing STEP.

The PDES Initiation Task and Report also included an Electrical Schematic Reference Model. The Initiation Task validated, through modeling, the concept that electrical connectivity and mechanical joining both shared a common underlying topology. This topological foundation found later application in electrical product modeling for both IGES and STEP.

5. HOW DID ELECTRICAL CONTENT FIND ITS WAY INTO AN ISO STANDARD[21]?

One might wonder how electrical content ended up in ISO, rather than an International Electrotechnical Commission (IEC) standard. As with STEP, the roots trace back to IGES. The original vision for IGES included easy access to all machine readable product data from any CAD tool, including data about electrical and electronic products. In 1981, more than a dozen extensions were proposed so that electronic uses of general-purpose CAD systems could be accommodated. These extensions reached consensus in May of 1982 for inclusion in Version 2.0. Electrical connectivity, however, proved difficult to implement as originally defined in IGES. Under the leadership of the IGES Organization Electrical Applications Subcommittee (EAS)[5], developers began using information modeling in 1983 to improve the quality of electrical constructs. Revised extensions for connectivity were approved in July 1984, and included in IGES 3.0. The EAS had tested the extensions (and the information models) through a functional circuit board designed in Minneapolis and sent as an IGES file to Albuquerque where two hundred undrilled copies of the board were manufactured. A few years later, a few boards with plated through holes were manufactured from the old IGES file. Two of the boards were sent to NIST where parts were assembled onto it, and the assembly's functionality verified.

Apart from the quality of the constructs, the EAS was concerned about overlap and duplication with other standardization efforts. In late 1983, the EAS met with the Institute for Interconnecting and Packaging Electronic Circuits (IPC) in an attempt to coordinate efforts. It was decided then that IPC would continue to focus on the CAD to CAM interface and the IGES EAS would focus on modeling and CAD to CAD issues. Members of the EAS also heard of attempts by a silicon foundry to develop an interchange format for Integrated Circuit (IC) designs, and many wondered if that effort would duplicate, complement, or conflict with what was being developed for IGES.

[5] Later renamed Electrical Applications Committee (EAC).

5.1 HARMONIZATION ACTIVITIES

In April 1984, the Institute of Electrical and Electronics Engineers (IEEE) Standards Coordinating Committee called a meeting that further drew the IGES Organization into a dialog with other standards efforts. Of particular interest was closer coordination between IGES and the relatively new Electronic Design Interchange Format (EDIF) effort. The EDIF representative declined an offer of joint participation, for fear that standardization activities might delay the EDIF development schedule—a factor that has continued to impede, from both sides, true coordination among related standards efforts. Other electrical standards represented included the IEEE Very High Speed Integrated Circuit (VHSIC) Hardware Description Language (VHDL)[6], the Abbreviated Test Language for All Systems (ATLAS), and the Tester Independent Support Software System (TISSS).

At about the same time, a representative from Westinghouse began reaching out to other related standardization efforts across the Atlantic Ocean, and authored several related papers that were published by CAM-I. He developed contacts that led to discussions between the IGES EAS and the International Electrotechnical Commission (IEC) Technical Committee 3, Documentation and Graphical Symbols (TC3). In particular, a representative from NBS along with other IGES officers attended a meeting of TC3 subcommittee SC3B in Los Angeles. Working Group 2 of SC3B had published the proposed standard on Interchange Technique for Documents of Electrotechnical Systems (ITDOES). This later facilitated the involvement of TC3 in the ISO/IEC Joint Working Group with ISO TC184/SC4.

Many organizations, including ANSI, and numerous individuals tried to find ways to increase the awareness and cooperation among related electrical standardization efforts with little measurable success. Each group working on some aspect(s) of the standardization for electrical and electronic product data had a set of volunteers, their sponsors, and a clientele to whom they felt they owed their scheduled deliverables. For the most part, no two efforts were initiated with the same goal, but rather extended into overlapping territory in response to the needs of their users. Furthermore, some of the sanctioning standards bodies depended in some part for revenue from the sale of standards documents. A certain amount of jealousy about which organization might seem subservient to which other organization also hampered some of the willingness of people at the working level to share results and efforts. The resulting array of conflicting and overlapping standards prevented the market from supporting any cohesive standard interchange methodology, and left much of the burden of data exchange on the shoulders of manufacturers who used CAD systems.

In February 1988, ANSI/ASME Y14.26 (the same committee that standardized IGES) raised the concern to ANSI management in a letter that stated:

> "...we are concerned that there are concurrent overlapping standards activities that are not coordinated. Of particular concern are the Initial Graphics Exchange Specification (IGES) Electrical Application subset, the Electronic Design Interchange Format (EDIF), the Institute for Interconnecting and Packaging Electronic Circuits (IPC) 35X series of specifications and the VHSIC Hardware Description Language (VHDL)...[22]"

While the standards cited were not the only efforts of concern, they were specifications that ANSI itself had authorized and that the government called out in their Computer-Aided Acquisition and Logistics Support (CALS) standards. This letter led to a "Harmonization" meeting at EIA Headquarters in May 1988. CAM-I's Electronics Automation Program (CAM-I EAP) manager followed by offering to champion the effort. Participants included Boeing, McDonnell Douglas, Allied Signal, Eastman Kodak, Hewlett-Packard, Northrop, The Plessey Company, Westinghouse, and NIST. In February of 1989, the EIA issued results of an evaluation report entitled "Harmonizing CALS Product Data Description Standards [23]." The report evaluated each of the four ANSI standards against 58 steps of the design process across four levels of product [24]:

> *Component:* Items that are usually packaged as an indivisible unit, to be assembled on a board or substrate.
> *Board:* An assembly of components on a board or substrate.
> *Box:* An assembly of one or more boards to implement a complex function.
> *System:* A functionally complete assembly of components, boards, and boxes.

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[6] Authorized by IEEE Project Authorization Request (PAR) P1076.

The CALS/EIA Report found "...far more overlap than...anticipated.... EDIF overlaps one or more other standards 78 times." The Report created a matrix showing which lifecycle steps were captured by which of the four ANSI standards, carved out a scope for each standard based on this matrix, and declared "harmonization" effectively accomplished. This proposed solution was rejected by industry, as noted in a subsequent CAM-I report [25] that criticized the report's conclusions. An industry member of ANSI Y14.26[7] summed up industry's viewpoint in a letter to ANSI in 1989:

> "An electronics company which performs all the steps in the design process...using heterogeneous computer systems, work stations, and factory NC [numerical control] machinery and robots would have to support all four standards.... At worst, this could mean not only having to implement the software to support each standard, but also having translators between each pair.... Such an approach (if it were feasible) would be cumbersome, error-prone, time-consuming, and costly."

In November 1989, NIST accepted the leadership of the Harmonization effort, which was later formalized as the Harmonization of Product Data Standards (HPS) organization under the Industrial Automation Planning Panel (IAPP) of ANSI. The HPS established three councils (to which NIST continued to serve as the Secretariat): Business Needs and Planning, Standards Development and Coordination, and Tools and Technology. McDonnell Douglas, then NIST, led the Tools and Technology Council.

The major accomplishments of the HPS organization were to propose a methodology and a process for harmonizing the four ANSI standards, and to publish the first version of a coordinated information model as ANSI/HPS-100 "HPS Information Federated Model Descriptions." Figure 4 and Table 1 show the strategy that HPS followed in hope to achieve harmonization; note the group's intent to standardize the "Consensus Conceptual Model" within the ISO STEP standard [26].

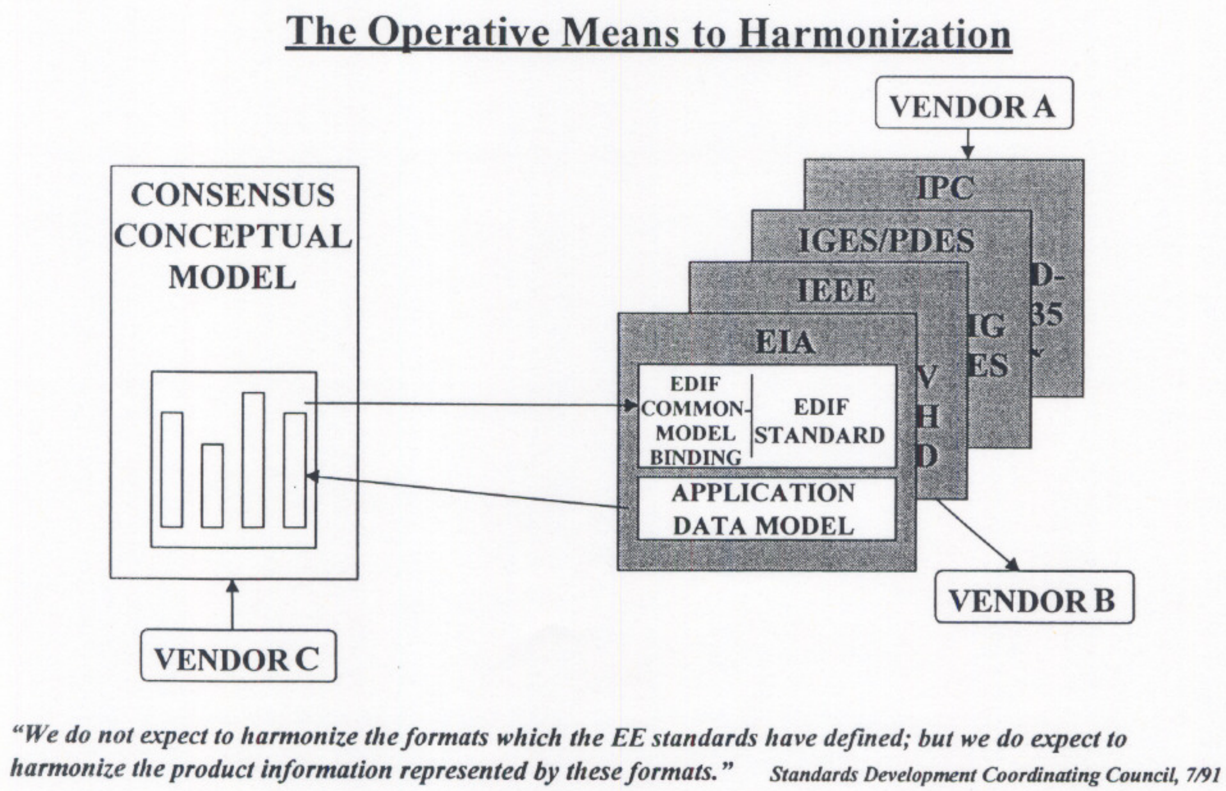

Figure 4. "The Operative Means to Harmonization"

[7] Milton Piatok, Boeing.

The HPS proposed the following process to guide harmonization, which reflects the group's early belief that the four standards would eventually be completely represented within STEP [27]:

Process	**Guidance for Harmonization**
Gather Models	Gather verified conceptual models for the subject area of current focus from each of the relevant standards organizations.
Federate	Every element is added to the federated model in the data dictionary. Elements are classified. Unique identical and conflicting coverage is identified. Conflicts are resolved by creating generic elements that each conflicting element can be mapped to. The Federated model contains each conflicting element as well as resolving elements.
Test	Define mapping between standards through the generic portion of the federated model. Create test vehicles (test cases) for the subject area of interest in the original standards run test: Sending Standard Format ⇔ Federated Model ⇔ Generic Portion of Federated Model ⇔ Federated Model ⇔ Receiving Standard Format Compare before and after files of test vehicles document mappings.
Harmonize	Derive harmonized model from tested, generic portion of federated model.
Submit for Standardization	Submit portions of harmonized model as candidate application reference models (ARMs) in STEP as they are ready. The harmonized model may also be submitted for national standardization. Hold public review.
Integrate with STEP	The portions of the harmonized model submitted for standardization within STEP will be integrated with STEP resource models in accordance with STEP procedure.
Develop APs, CDIMs	Develop application protocol (AP) and context-driven information model (CDIM) for subject area of interest. The AP will reference the mappings between the harmonized model and each standard. Identify information voids that none of the standards cover.

Table 1: The Harmonization Process (V1.1)

Both the information model and the guidelines for harmonization, later referred to as the "federation" to reflect the individual organizations' priority of autonomy, aided the groundwork for continuing international collaboration. The HPS was moved under the CIM Standards Board of ANSI and then deactivated as leadership in the area was transferred to the international arena under IEC Technical Committee (TC) 93. Through its working groups, IEC TC93 continues to develop a federated model to aid in the interoperation among electrical information exchange standards. NIST representatives continue to play an active leadership role within IEC TC93 to build supporting electrical and electronic standards.

5.2 IGES ELECTRICAL TRANSITION TO STEP

Although IGES continues to be deployed in industry, STEP is intended to address its weaknesses and provide the industry with a broader, more robust standard. To help interested manufacturers prepare their people for Computer Integrated Manufacturing using STEP, the IGES Electrical Applications Committee (EAC) coordinated work of two successive Cal Poly Task Teams. The first [28] developed an information model of electrical connectivity, the second [29] a model of layered electrical products, such as a printed circuit board (PCB). The latter report included a computer diskette containing a demonstration of the model's implementation. This demonstration was given before an ISO plenary session in 1988, and proved the viability of modeling as the basis for real-time database retrieval as well as information exchange. The final reports of both teams included EXPRESS models which were later incorporated in the "STEP Tokyo Draft" [30] in 1988. These Task teams were sponsored by the Air Force together with several aerospace companies.

A notable monetary and morale boost came from the Navy Command, Control & Ocean Surveillance Center, Research Development Test & Evaluation Division, which funded research to greatly increase the accuracy of the transfer of Hybrid Microcircuit Assemblies (HMA) design information to manufacturing using IGES. The results of this project were published as the Initial Graphics Exchange Specification Hybrid Microcircuit Application Protocol [31]. Some of the theory developed by the Cal Poly Teams for STEP was also used to develop the Application Reference Model for the HMA application. However the Application Interpreted Model (AIM) was not in

EXPRESS, but was comprised of a collection of IGES entity objects. This AIM benefited greatly from a funded analysis of the major ECAD systems' data structures as found in translator software.

As the IGES HMA was being reviewed within the EAC, work had begun work on an electrical AP within the STEP standard, referred to as AP 210. In recognition of industry's reliance on IGES for electrical data exchange, and the uncertain schedule whereby STEP AP 210 would be released, the EAC resolved[8] to standardize an IGES Layered Electrical Product (LEP) AP based on the HMA work. This effort was initially led by the Department of Energy's Sandia National Laboratories and later by NIST[9], and represented the cumulative effort of over a decade of work by scores of volunteers. The EAC strived to serve as a collaboration point, so that the evolving IGES LEP AP and the STEP AP 210 [32] could share a common technical foundation. The LEP AP referenced IGES Version 5.3 [33], and drew its name from the model contained in the Cal Poly Task Team Extension Final Report.

6. THE IGES LEGACY

Even before the ANSI/HPS-100 model emerged, the early efforts of the IGES Electrical Committee provided some valuable general lessons learned about information modeling in a standard's setting:

- Team diversity. Need varied backgrounds (programmers, DBMS, subject matter experts, suppliers, customers, testers, a facilitator, scribes and visionaries)
- Committee resources. Need stable work force (of 6 to 12 people) having committed resources.
- Trained team. Need trained participants; otherwise, frequent methodology training (for newcomers) slows development.
- Strong leadership. Need knowledgeable oversight.
- Long-term commitment. Need long term commitment from management.
- Active communication. Need frequent and timely communication within the team.
- Strong public relations. Need public awareness of intent, schedule, and scope of effort.
- Information modeling. Information modeling is not easy, but it seems necessary, though not sufficient, for Computer Integrated Manufacturing (CIM).

The development of IGES showed that Standards can be produced quickly when the climate is ripe. What makes a "ripe" climate?

- The standard has a very limited scope.
- A short contractual deadline exists.
- The playing field for consensus-building is relatively small—only a few CAD vendors in existence and only a few users applying CAD technologies.
- A high level of dedicated buy-in exists.

The technical legacy from IGES alone was plentiful for the next generation of product data standards:

- Requirements must be documented.
- Subsets are inadequate and application protocols are needed [34][35][36].
- Product data exchange standards need to have enhanced functional capabilities, including:
  - Context and viewpoint (presentation does not equal meaning).
  - Unambiguous semantics.
  - Three-dimensional (3D) solid model exchange (for mechanical parts).
  - 3D tolerancing and dimensioning.
- Assessing compliance to the standard is necessary.
- A migration path for legacy systems is a must.

[8] In the EAC's "Mesa Resolution" of January 1994.

[9] Under Larry O'Connell of Sandia, and then Curtis Parks of NIST.

7. SUMMARY

The technical development of IGES, related non-US standards, the harmonization initiative, and the development of STEP are inseparable from the development of the relationships among the contributors. There was tremendous excitement among the early developers about embarking on new territory. Passions ran high. Vendors learned early that by opening up their systems to the public they could more readily catch a market—not lose it. Late-night conversations in smoke-filled rooms played a critical role in the birth of these early standards, as did personal trust among the participants. Once feasibility was shown through these early exchange standards, the tremendous need within industry for a formally standardized CAD exchange capability drove the world to development efforts such as STEP. These early pioneers had little idea of the magnitude and longevity of the efforts that would follow their lead.

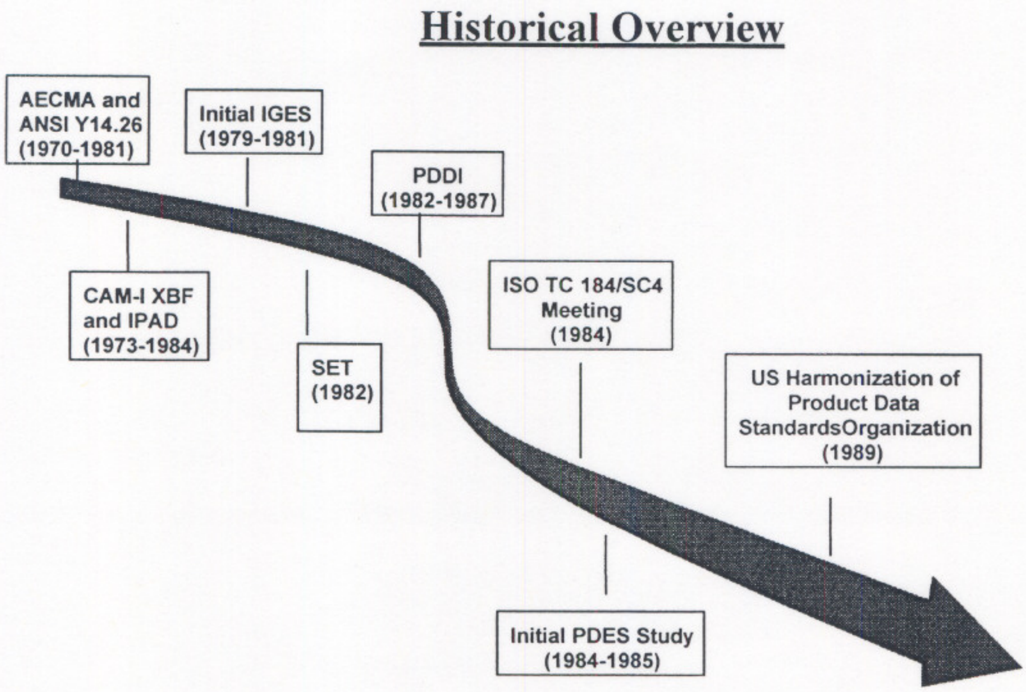

Figure 5. "Historical Overview."

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