An Architecture of Adaptive Product Data Communication System for Collaborative Design

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***Abstract*—Today, designers and engineers on collaborative design environments often work in parallel and independently using different tools distributed at separate locations. Due to unique characteristic of engineering design, interaction during product development is difficult to support. As the information and communication technologies advances, computer supported collaborative design (CSCD) becomes more promising. Nevertheless, a potential problem remains between the product design and manufacturing, which mainly lies on the geometric shape of products that exists inherent in mass-customization. Meanwhile, CAD/CAM technologies have their own authoring tools, which govern the use of independent language and format for expressing various features and geometry. This condition creates incompatibility and has significant impact to the product costs. This paper is to address the incompatibility problem by introducing an architecture of the adaptive product data communication system. The adaptive system has a capability for autonomous tracking of design changes. The tracking model supports forward and backward tracking of constraint violation during the collaborative design transactions.**

Keywords-computer supported collaborative design; product data communication; adaptive.

I. BACKGROUND

Today's industry requires massive computer-supported technologies to address the increasingly complex product development tasks and the high expectations of customers. As the information and communication technologies advances, application of collaborative engineering to product design, so-called computer supported collaborative design (CSCD), becomes more promising.

Sprow [1] defines CSCD, or so-called cooperative design, as the process of designing a product through collaboration among multidisciplinary product developers associated with the entire product life-cycle. CSCD is carried out not only among multidisciplinary product development teams within a company, but also across the boundaries of companies and time zones, with increased numbers of customers and suppliers involved in the process.

Accomplishing a design task and delivering the results to manufacturing requires huge and complex information. Meanwhile, a potential problem remains between design and manufacturing, which mainly lies on the geometric shape of products that exists inherent in mass-customization [2]. Since the CAD/CAM technologies mostly govern independent authoring tools in different languages and formats, this condition creates incompatibility and has significant impact to the product costs. Therefore, synchronization of product data along the product development life-cycle is necessary.

This paper is to address the incompatibility problem that usually occurs in a collaborative design team by introducing an architecture of the adaptive product data communication system. The adaptive system is developed based on cloud computing technology, whereby shared servers provide resources, softwares, and data to designers and engineers on remote nodes on demand. Section 2 provides the framework of CSCD, Section 3 describes the architecture of the adaptive product data communication system, Section 4 describes the system ability for tracking of design changes, and, finally, Section 5 summarizes the conclusion of the paper.

II. COMPUTER SUPPORTED COLLABORATIVE DESIGN

Many researchers consider CSCD as an application of computer supported cooperative work (CSCW) in design. The term CSCW was first used by Greif and Cashman in 1984 to describe the topic on how to support people in their work arrangements with computers [3, 4]. Design has been one of the most important applications of CSCW technologies. With the rapid advancement of Web-based technologies, CSCD has progressed dramatically. The depth and breadth of CSCD applications are far beyond the traditional definition of concurrent engineering.

Technologies like CSCW and intelligent agents have been investigated to be effective to enhance communication, cooperation, and coordination among design team as well as software tools. The CSCW tools like *groupware* are used to facilitate communication among users. Meanwhile, in CSCD an *agent* can be considered as a software system that communicates and cooperates with other software systems to solve a complex problem, which is beyond the capability of each individual software system [5].

A. Web Technology for Collaborative Design

Since its emergence in 1993, Web has been quickly applied in the development of collaborative design systems. Along with the Web, a number of associated representation technologies have been developed, such as Hyper Text Mark-up Language (HTML), eXtensible Mark-up Language (XML), and Virtual Reality Mark-up Language (VRML), to enable better cross-platform and cross-enterprise exchange of multimedia information and design models. Many early collaborative design systems were developed using the Blackboard architecture [6] and distributed-object technologies like CORBA (Common Object Request Broker Architecture) [7], COM (Component Object Model) [8], and DCOM (Distributed Component Object Model). A blackboard architecture is a distributed computing

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architecture where distributed applications, modelled as intelligent agents, share a common data structure called the "blackboard" and a scheduling/control process.

B. *Integration of Web and Agent Technologies*

A CSCD system developed with the Web as a backbone will primarily provide access to catalogue and design information on components and sub-assemblies, communication amongst multimedia formats, and authenticated access to design tools, services and documents. With the development of Web services and Semantic Web technologies, Web-based infrastructure has been used in a number of collaborative design systems. A Web-based collaborative design system usually uses a client/server architecture, in which the interaction between components is predefined. This kind of approach is considered insufficient to support dynamic collaborative design, where tasks are usually involving complex and non-deterministic interactions, producing results that might be ambiguous and incomplete. Hence, integration of Web and agent technologies to support collaborative design is considered crucial.

Software agents are mostly used for supporting cooperation amongst designers, enhancing interoperability between traditional computational tools, or allowing better simulations. An agent-based collaborative design system is a loosely coupled network of problem solvers that work together to solve complex problems that are beyond their individual capabilities [9]. Software agents in such systems are communicative, collaborative, autonomous, reactive (or proactive), and intelligent.

To date, many agent applications in the Web-based collaborative design still face many challenging questions. Coping with this issue, the concept of active Web server is introduced to integrate the Web and agent technologies [10]. The active Web server has driven the emergence of Web services concept [11]. As stated by the World Wide Web Consortium (W3C) [12], a Web service is a software system designed to support interoperable machine-to-machine interaction over a network.

III. Architecture Of Adaptive Product Data Communication System

In this section, an adaptive product data communication system is being introduced. The adaptive system is designed using an integrated Web and agent-based technologies for coordination in collaborative design environment. Here the term "adaptive" represents the ability of the agent to adapt with changes in the Web-based environment that commonly source from changes of application programs, data formats and structure, in such a manner in order to improve the system's future performance.

Design collaboration requires a higher sense of working together in order to achieve a holistic creative result [13]. It is a far more demanding activity, more difficult to establish and sustain, than completing a project in cooperation or coordination. Here the architecture of the adaptive communication system is designed based on STEP [2, 14], i.e., Standard for the Exchange of Product Model Data. STEP is an ISO standard for the computer-interpretable representation and exchange of industrial product data. The system architecture contains a shared product database management system (DBMS), which is composed on a low-level language, i.e., ASCII (American Standard Code for Information Interchange), as its native format. The database consists of geometry, topology, and auxiliary information. Considering complexity of engineering objects, a "reference" of geometry and topology is built into the DBMS that consists of taxonomy and data dictionary of elements geometry.

A. *Taxonomy*

The taxonomy is designed to be generic that workable under a variety of CAD applications. As a reference, the taxonomy has two functions. First, it identifies and generates particular geometric shapes. Second, it classifies the geometry into specific groups of objects (e.g., crankshaft, cantilever, motor-body, etc.). Fig. 1 describes the hierarchical structure of object classes, features, faces, and geometric entities in the parent-child relationship.

B. *Data Dictionary*

Data dictionary is a centralized repository of information about such data like meaning, relationships to other data, origin, usage, and format [15]. Data dictionary refers to a piece of "middleware" that supplants the native format of DBMS. Software agents are implant in the middleware in HTML, XML and VRML formats as interface to the CAD/CAM (i.e., Inventor and solidworks) applications. The middleware is modelled as an active object-oriented database (OOD). The active OOD is a database that allows users to specify actions to be taken automatically given certain rules when certain conditions arise [16]. In this architecture, the data dictionary is developed as an active semantic network (ASN) and realized as an active OOD. ASN is a shared database system developed to support designers during product development [17]. The goal of ASN is to represent all knowledge relevant to the collaborative product design teams. Fig. 2 describes the data dictionary in the ASN architecture.

C. *ISO/OSI Data Communication Network*

Since each CAD/CAM system has different proprietary native formats, data communication in collaborative design team should be done on a neutral format, i.e., .STEP file. The terms "neutral' means that the file format is independent of different formats utilized by the various computer-aided systems. Here the data communication network is designed based on the seven-layers ISO/OSI model as depicted in Fig. 3. An ISO/OSI model is an Open System Interconnect (OSI) model developed by the International Standards Organization (ISO). Therefore, this model is considered fit to the STEP standard. The model splits the communication process into seven layers, i.e., physical, data-link, network, transport, session, presentation, and application layers.

The physical layer deals with the electrical and mechanical means of data transmission. Data-link layer frames across a single local area network (LAN) and its

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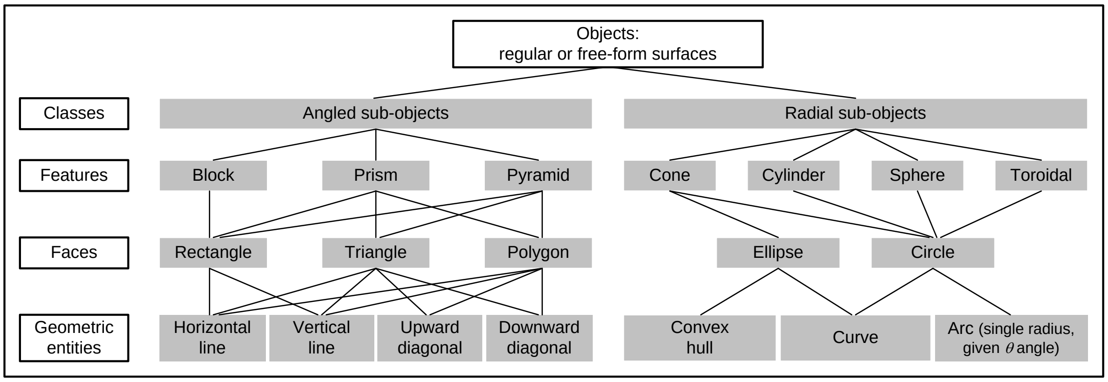

Figure 1. Taxonomy.

functions include resolution of contention for use of the shared transmission medium, delimitation and selection of frames addressed to this node, detection of noise via a frame check sequence, and any error correction or retries performed within the LAN. Network layer provides the transparent transfer of data between transport entities. Transport layer ensures that data units are delivered error-free, in sequence, with no losses or duplications. Session layer controls the dialogue between applications during a communication session. Presentation layer takes care of the syntax of the data exchanged between applications. Finally, application layer ensures that data transferred between any two applications are understood. Each layer can be developed independently and replaced without affecting the other layers.

When data is sent from workstation A to workstation B, it goes down the layers. At each layer, a control message is appended to the data. Then, the complete data is transmitted through the ISO/OSI medium to workstation B. At each layer of workstation B, the control message is stripped and proper actions are taken to convert the data into the proper format. Through an efficient data communication, conflicts and constraints can be analyzed earlier from different perspective. Hence, the collaborative design team can achieve the design objectives for an optimal product performance, at low manufacturing costs, and assurance that the product can easily and economically be serviced and maintained [18].

IV. TRACKING OF DESIGN CHANGES

One of the issues in collaborative design is that one must assess the impacts of a design change on other design objects and notify other parties promptly [19]. This paper adopts an approach to tracking of design changes introduced by Xie [20].

The mechanism for tracking of design changes is based on product data and their relationships. The product data contains descriptions for product specification, function decomposition structure, solution principles, layout design, assemblies, and parts. The relationships are established based on geometric constraint between two or more elements. The geometric constraint relationships define three types of constraint between parts, i.e., fit, contact, and consistent constraints. The fit constraint exists if there is a tolerance requirement between parts. The contact constraint represents a physical contact between two parts. The consistent constraint exists if two parts hold a dimensional constraint without a physical contact.

This approach supports forward tracking and backward tracking of a design change. Forward tracking identifies the impact of the change on later design stages if a design change occurs at an earlier stage. On the other hand, backward tracking identifies the impacts of changes on previous stages, if a change occurs at a later stage. The design change rules are stored in a knowledge base so that all the impacts can be retrieved through an inference engine. Therefore, designers can identify the total impacts of a proposed design change on an entire product development life-cycle.

To make the necessary design information available, product data information is extracted from design process and represented in a data model. A data model is a set of concepts that can be used to describe the structure of DBMS [21]. Here an entity-relationship model is used to describe the concepts of entities, attributes, and relationships.

In this regard, the change tracking model involves five entities, i.e., *Specification*, *Function*, *Principle*, *Design_ object*, *Assembly*, and *Part*. These entities are associated to 19 attributes, i.e., *Buy-or-make*, *Category*, *Classification*, *Cost*, *Criteria*, *Description*, *Dimension*, *High-limit*, *ID*, *Low-limit*, *Mass*, *Materials*, *Measurement*, *Quantity*, *Selected*, *Source-form*, *Tolerance*, *Type*, and *Unit*. Meanwhile, the relationships represent a set of associations amongst entities. Cardinality ratio constraints specify three common combinations for binary relationship types, i.e., one-to-one (1:1), one-to-many (1:M), and many-to-many (M:N). The relationships in this model include *Requires*, *Contains*, *Previous*, *Solution*, *Implement*, *Belongs*, and *Constraint*. Fig. 4 describes the entities and their associated attributes in the prescribed relationships.

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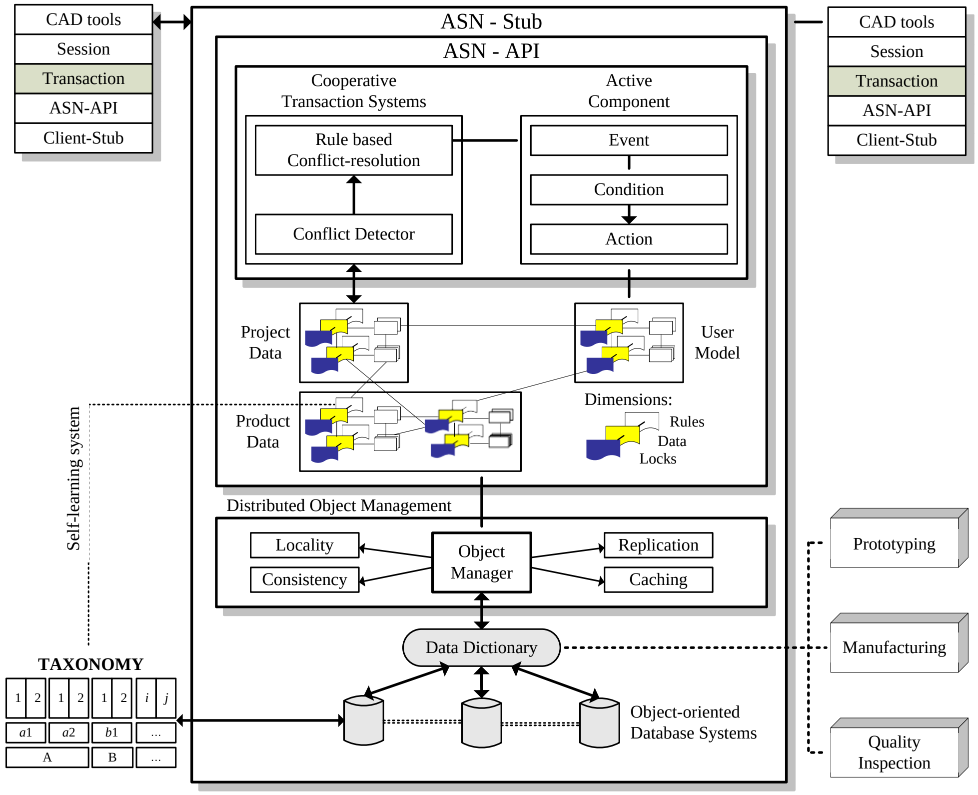


Figure 2. Data Dictionary In Active Semantic Network.

V. CASE STUDY

To verify the changes tracking model, a case study is applied on the motor-body. The initial design of motor-body has cylinder shape with 1.751 kg mass and 0.000227 m^3 volume of alloy steel (SS). The real structure sustains a distributed state of stress. The stress is represented by forces at the element joints or nodes. Correspondingly, the displacement of these points is employed in the characterization of displaced state of the element.

Generally, structural analysis problem can be treated as linear static problem under assumptions small deformation (i.e., loading pattern is not changing due to the deformed shape), elastic material (i.e., no plasticity), and static load (i.e., the load is applied to the structure in a slow of steady operation). Therefore, the force-displacement analysis is applied to the motor-body. The relationship between the joint forces and the joint displacements of finite elements should satisfy the stiffness function,

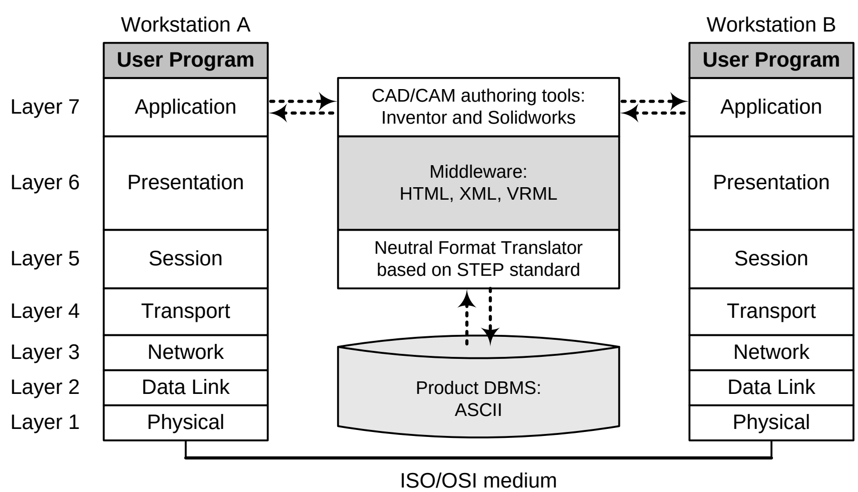


Figure 3. ISO/OSI Data Communication Network Model.

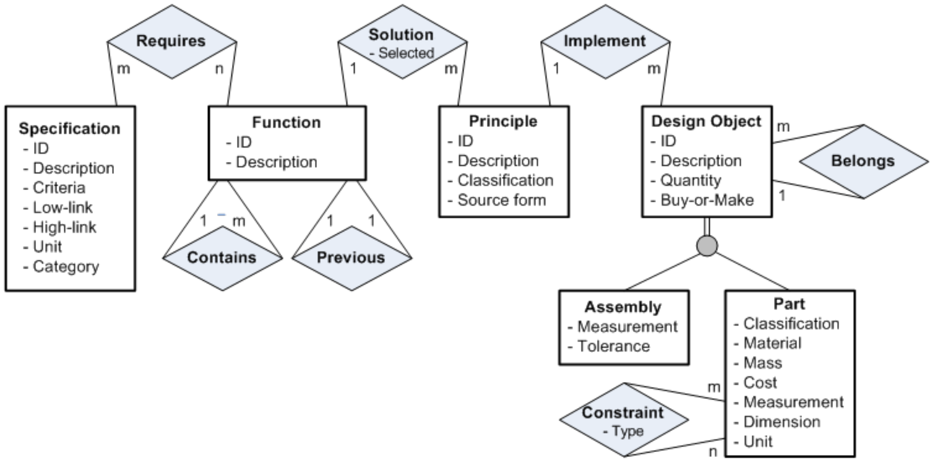


Figure 4. E-R Diagram For Change Tracking Model (Source: Xie [19]).

$$\{F\} = [k]\{\Delta\} \qquad (1)$$

where {F}: element force, {Δ}: displacement vectors, and [k]: element stiffness matrix. An individual term of the [k] matrix, k_{ij}, is an element stiffness coefficient. When the displacement Δ_j is imposed at unit value and all other degree of freedom are held fixed against displacement ($\Delta_k = 0$, $k \neq j$) the force F_i is equal in value to k_{ij}.

The force-displacement analysis produces an average deformation scale at 1.72501e^{+008} and prediction of location where the most deformed mesh are possible to occur. The resultants displacement shows the minimum condition 0 mm is at location (3.969 cm, -0.499 cm, -11.000 cm) and the maximum condition 6.76612e-008 mm at location (-3.373 cm, -3.291 cm, -0.099 cm). The analysis predicts that two most possible deformed locations likely to occur at the lower-part of cab-screw holes as depicted in Fig. 5. This condition makes the cylinder shape has more possibility to slip from its position and fixtures.

Furthermore, the Von Mises stress [22] analysis is applied

$$\sigma_e = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \qquad (2)$$

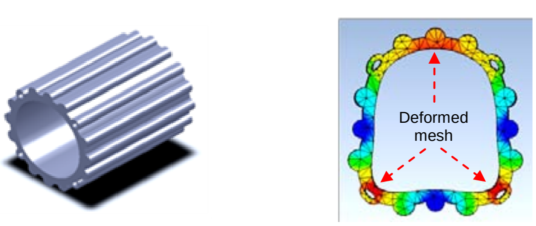
where σ_1, σ_2, and σ_3: three principle stresses at the considered point in a structure. For a ductile material, the stress (σ_e) and the yield stress of the material (σ_y) must satisfy the constraint

$$\sigma_e \leq \sigma_Y. \qquad (3)$$

The results estimate minimum stress 3.04976e^{-006} N/mm^2 (MPa) at location (4.170 cm, -0.470 cm, -6.750 cm) and maximum stress 0.000572322 N/mm^2 (MPa) at location (3.524 cm, -3.385 cm, -0.350 cm). The stress is distributed from the inner cylindrical mesh boundary to the outer boundary with the highest strained locations are found at the elements adjacent to the four cab-screw holes. This condition makes the initial design has high potential failure during the assembly and product use. Therefore, it needs to be redesigned.

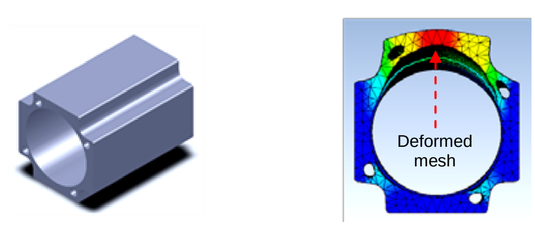
In this regard, design improvement is done based on entities, attributes, and relationships which have been defined in the E-R diagram. Change of *Design_object* from cylinder to block shape has driven change of specification, part, and assembly respectively. The progress for forward tracking of *Design_object* change is described in Table I.

As a result, a block shape of motor-body in dimension 82.5 x 82.5 x 100 millimeters with 1.859 kg mass and 0.000241 m^3 volume of alloy steel (SS) is obtained. The new design has 6.15% more weight than the initial design, but shows better performance. The force-displacement analysis of the new design produces an average deformation scale 8.59488e^{+007}, i.e., 50.18% better than the initial design. In the new design, the deformation has been localized at the upper-front to -middle of finite mesh as depicted in Fig. 6. Moreover, the von Mises stress analysis shows the results of minimum stress 3.43238e-^{007} N/mm^2 (MPa) and maximum stress 0.00139487 N/mm^2 (MPa). These structural problems are expected to be further minimized during assembly when the motor-body is joined with the motor-cover.



(*a*) cylinder shape (*b*) estimated displacement

Figure 5. Initial Design



(*a*) block shape (*b*) reduced displacement

Figure 6. Improved Design

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TABLE I. FORWARD TRACKING OF DESIGN OBJECT CHANGE

ENTITIES	ATTRIBUTES	STATUS	DESIGN VALUES	
			INITIAL	IMPROVED
Function	ID	No change	part#1	part#1
	Description	No change	Motor-body	Motor-body
Principle	Classification	No change	Motor protection	Motor protection
	Source Form	No change	Production house	Production house
Design_Object	Quantity	No change	100 pieces	100 pieces
	Buy-or-Make	No change	make	make
Specification	Criteria	No change	mechanic – static	mechanic – static
	Low-limit	Change	3.04976e-006 N/mm^2	3.43238e-007 N/mm^2
	High-limit	Change	0.000572322 N/mm^2	0.00139487 N/mm^2
	Unit	No change	1	1
	Category	No change	automotive part	automotive part
Part	Material	No change	alloy steel (SS)	alloy steel (SS)
	Mass	No change	min 1.750 – max 1.860 kg	min 1.750 – max 1.860 kg
	Cost	No change	USD 367.82 - USD 375.00	USD 367.82 - USD 375.00
	Measurement	No change	millimeter (cm)	millimeter (cm)
	Dimension	Change	d∅: 82.5mm, ℓ: 110 mm	w: 82.5 mm, h: 82.5 mm, ℓ: 110 mm

VI. CONCLUSION

Today, design activity is inevitable should be done as an integrated process with design optimization and manufacturing. In a collaborative design environment, the product development activities usually take place at geographically distributed locations.

This paper introduces an adaptive product data communication system that is developed by making used of the integrated Web and agent-based technologies. The architecture of the adaptive system is designed based on STEP standard. The system contains a shared product database management system (DBMS), which is composed on a low-level language as its native format. Meanwhile, the data communication network is developed based on the seven-layer ISO/OSI model. Considering high possibility of constraint violation during the collaborative design transactions, a capability for autonomous tracking of design changes is built in to the adaptive system. The tracking model supports forward and backward tracking of design changes. Therefore, it enables designers and engineers to identify the total impacts of a proposed design change on an entire product.

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