Engineering Change Propagation System using STEP

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Abstract: Reducing the time for engineering changes can greatly shorten a product's life cycle and improve the productivity of enterprises. This work proposes an approach to engineering change propagation between CAD and product data management (PDM) systems. A system for modeling and triggering changes of models of engineering data, geometries, and features, using STEP AP 214 and AP224, is developed. A change in CAD and PDM systems can propagate along a defined path and trigger a rule by which data of another system are changed. The proposed engineering change propagation (ECP) system provides a flexible, virtually integrated framework to enable engineering change. Affected items and propagation sequences of engineering changes are inferred with the help of an ECP network. Engineering change issued between a STEP-based solid modeling system and a PDM system is implemented and discussed to demonstrate the capability of the ECP system. Change in the feature parameters of a CAD system is propagated and the relevant data, defined in the ECP network, are triggered. Enterprises can use the ECP system to integrate various information systems, such as CAx, PDM, CAPP, ERP, and others, and facilitate collaborative engineering using a virtual framework, to promote competition.

Key Words: engineering change, STEP, product data management, concurrent engineering, change propagation.

1. Introduction

Engineering change is an important part of concurrent engineering and considers all related activities during design and manufacturing stages to reduce product development time, stressing a parallel and collaborative approach to design. The approach is typically time-consuming since it frequently involves various information systems and issued frequently during product life cycle. This work proposes an approach to engineering change propagation mechanism between CAD and product data management (PDM) systems to shorten the time taken by engineering change. An engineering change propagation (ECP) system for modeling and triggering engineering changes in models of engineering data, geometry, and features using the STEP standard, is developed. Design changes issued in a CAD system can trigger an ECP network defined therein that system to process the engineering change activities and data change. By applying layers and abstraction, the system assists users to model engineering change propagation paths, ECP networks, and the connections with a database. The ECP system can be connected to various information systems, including CAx, PDM, ERP, and others, to extend its scope to cover all stages of a product's life cycle. In the ECP network model, changes in these systems can be communicated to trigger engineering change functions and change data instantaneously according to predefined rules to help engineers model, manage, and browse related engineering information. An example of engineering change between CAD and PDM system is given to verify the effectiveness of the ECP system. The change in STEP-based solid modeling system and PDM systems can be propagated along the path defined in the system and trigger the use of a change rule to alter the data of another system. Change in the features parameters of a CAD system is propagated and triggers the definition of related data defined in the ECP network, proposed in this paper.

2. Review

STEP AP203 [1], AP214 [2], AP224 [3] are used to represent data concerning product definition, engineering change, geometric and features, in defining an integrated product data model and thus facilitate engineering changes in engineering systems. Operations that involve between these entities definition must be defined, since these static data models represent data without defining functions or procedures. Meta-models of these data models and the ECP networking model proposed in this work are used to manage and connect the related databases. Meta-models have been recently researched and implemented to manage, manipulate, and integrate object-oriented data models

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[4–7]. This work applies the concept of meta-models to generalize all data models as instances of higher-level data models and represents them as a node in an ECP network.

Engineering change, using STEP-based data models as a kernel representation, bridges data manipulation gaps among various information systems [8–10]. Engineering information system, such as CAD/CAM, MRP systems, can interact with the developed STEP-based engineering data management system [11]. These approaches integrate the data models of information systems within product life cycles to support data manipulation caused by engineering change. To satisfy the design constraints and design objectives, various studies on constraint satisfaction of features and assembly are proposed [12–15]. The ECP network proposed here adopts STEP-based data models to integrate the information systems involved in engineering change, and to model the propagation path to enable users to define their change rules. The propagation operation can be complicated and may trigger parallel procedures since these constraints are defined in the propagation modeling stage.

3. Proposed Approach

The operation of the ECP system, including two main blocks each with several procedures. An ECP modeling block is used to define accurately the propagation path for engineering change. An ECP propagation block is employed to trigger and enforce rules of changed items from engineering change. ECP modeling involves five procedures. In top-level modeling, the scope of the information systems involved, and data schema of the related systems are modeled. In entity-level modeling, the class of data models and table definition of the database are defined. In instance-level modeling, the instances of data model, object, and database records are modeled. Entity and instance level data modeling can be performed by parsing the EXPRESS model in STEP or data schema of the database. ECP propagation path modeling is used to define the data relationship among various information systems. ECP direction modeling extends path modeling and is employed to define the direction of the propagation path and associated change rule. ECP network involve propagation paths with direction definitions.

Information systems that relate to engineering changes should have a STEP-based interface to manipulate insert, delete and modify operations and thereby be able to trigger the ECP network defined in the ECP system. The interface is used to trigger the corresponding data node in the ECP network when engineering change is issued. The ECP system determines the scope of change of affected items. The propagation path and the order of the changed items are inferred through the ECP engine. The defined procedures and rules of changed items in the ECP network are triggered to collaborate engineering change. The ECP system provides a flexible and virtually integrated framework to enable engineering change.

3.1 ECP Modeling

Figure 1 illustrates the user interface of the ECP system. It provides users with ECP modeling and propagation by manually dragging and dropping the node representing data in different systems. The left view of the system shows all data nodes and items affected by the engineering change. The right view is used to model the ECP network and analyze STEP EXPRESS models or database schema in ODBC service. The data nodes of various information systems are represented with different styles. The directed node links are used to infer the engineering change sequences of affected items.

3.2 STEP-based Interface

The integrated system architecture proposed by Urban [16] is employed in this paper to fulfill the access requirements of heterogeneous systems. Four kinds of integrating solutions, including loosely-coupled architecture, tightly-coupled architecture, and operational mapping, hybrid operational and structural mapping approaches, are considered. The fourth approach is used here. The object-oriented interface with the GCS data model is used to integrate various system environments. The scopes of the GCS data model include STEP-based data models of CAD and PDM systems. The STEP-based interfaces of CAD, PDM, and feature editing systems, enabling the access across heterogeneous systems, represent the object-oriented interfaces that use COM technology.

Core data models of the ECP system architecture with CAD and PDM systems in this work adopt integrated product-oriented data models that meet STEP standard. The data models of the CAD interface follow STEP AP203 and AP214, those of the PDMS interface follow the PDM schema. Those of the feature editing module follow STEP AP224 as illustrated in Figure 2. Figure 2(a) depicts the association of shape representation and feature definition used in CAD and feature editing systems, while Figure 2(b) presents the association of shape definition with property definition used to integrate data models of the CAD and PDM systems.

3.3 Inference for Engineering Change Propagation

The sequence of engineering change propagation is inferred by topological sorting and shortest path

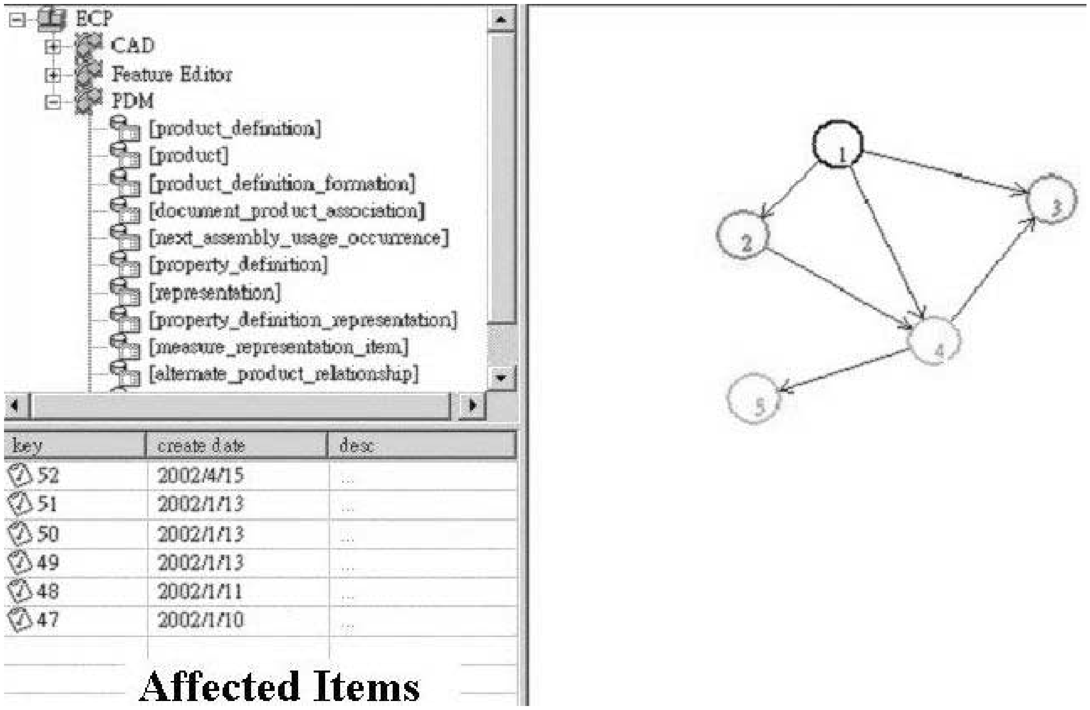
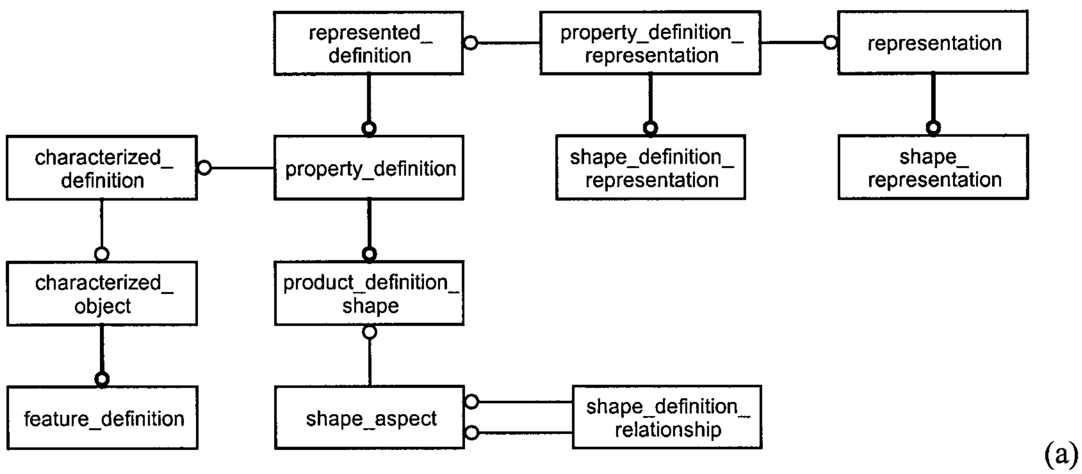


Figure 1. User interface of ECP system.



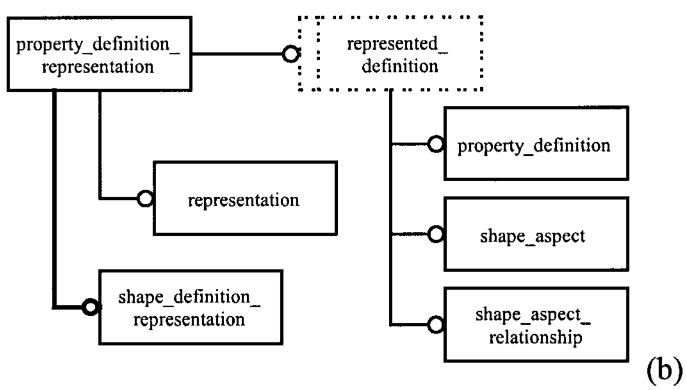


Figure 2. Core data model for STEP-based interface modules used in this paper.

methods. Topological sorting, using the directed graph structure, applies an AOV-network with activities on vertex network. Vertices in the network represent tasks or activities, and edges denote precedence relations of various activities. Edge E(Vi,Vj) implies that task Vj will be processed after task Vj is finished. The shortest path method uses the Dijkstra algorithm to consider the weighting of the edge that represents the time required to transfer one task to another. The directed network result is the shortest path that consumes minimum time. The result may differ with the weighting of the edge. Experience in evaluating task transfers is the major requirement for setting the weighting.

4. Implementation

This study explores engineering change between Spring solid modeling and STEP-based PDM systems, both are developed by Solid Modeling Laboratory, Mechanical Engineering Department, NTU.

4.1 System Architecture

Figure 3 illustrates the overall structure of the ECP system. CAD and PDM systems are all based on a three-tiered architecture, the lowest layer of which contains a database manipulation module connected to individual database. The ODBC protocol and the CRecordset class of MFC are applied to the database manipulation modules of these systems. Two additional modules, CADDBManager and PDMDBManager, are utilized to handle the engineering change transaction when a change is issued. When a design change issued in the CAD system, the CADDBManager searches and triggers ECPDBManager, which manages the database of the ECP system. ECPDBManager obtains the ECP network of the affected data node and fetches all the changed items in the CAD and PDM systems. The ERP system then enables engineering change to propagate from CAD to PDM.

The STEP-based interface of CAD, feature editing, and PDM systems apply COM technology to facilitate interoperation. Functions defined by these systems are declared public and compiled as COM automation documents. The client can invoke a public interface to access the function defined in the server. The automation server inherits IUnkown and IDispatch interface in the MFC class and provides clients with public methods to call automation objects.

The operation of the ECP network in this study relies on the COM-based change propagation trigger mechanism in the ECP system. The ECP trigger module, CAD, feature editing, and PDM systems are all COM automation object servers that can call and be called by other COM automation objects. When an engineering change to the diameter of a bolt is implemented and committed in the CAD system, the feature editing system invokes an automation object of the ECP system to retrieve and calculate the resulting ECP network. A directed network is determined by either topological sorting or the shortest path method. Related nodes in the network are considered to trigger their automation objects and methods in sequence.

4.2 Usage Scenario

The major points of operation of the ECP system proposed here can be discussed by considering two usage scenarios: engineering change propagation modeling and triggering. Figure 4 presents the operational sequence for engineering change propagation modeling,

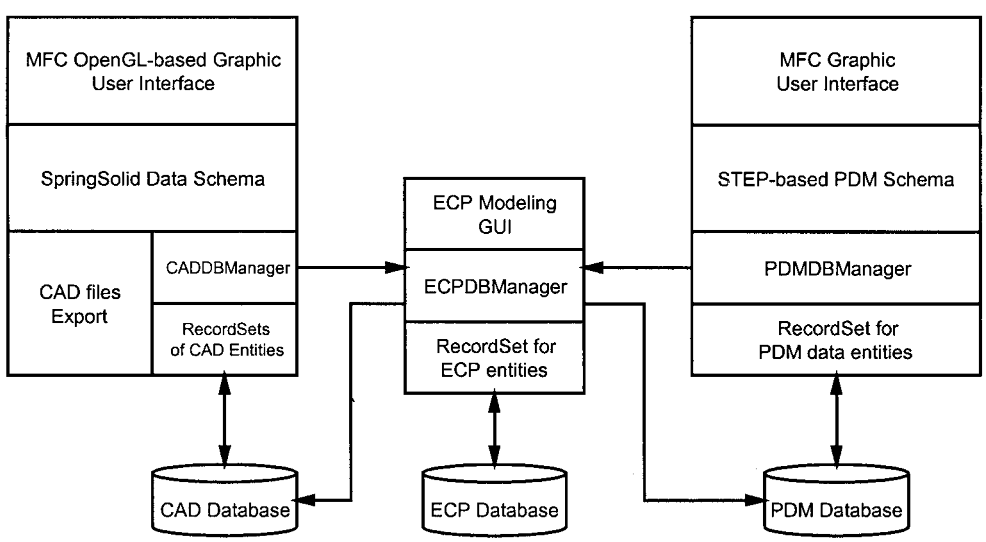


Figure 3. The ECP system architecture.

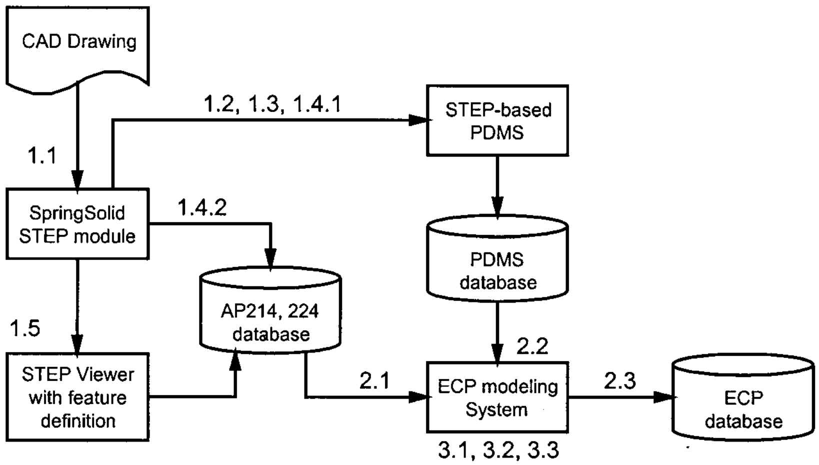


Figure 4. Operation sequence for engineering change propagation modeling.

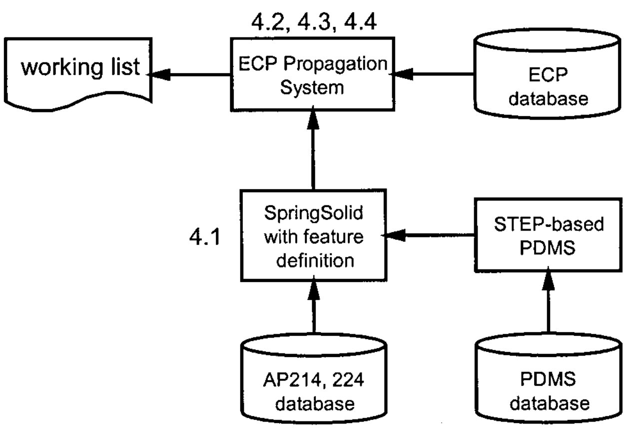


Figure 5. Operation sequence for engineering change propagation triggering.

and Figure 5 shows the sequence for engineering change propagation triggering. The sequence number shown in the figure can be used as the sequence defined in interaction diagram of UML modeling.

CAD models are initially imported by the STEP module of the Spring solid modeling system first to read the product structure and geometric information (1.1). The CAD system then calls the PDM system's automation object and checks the product definition information (1.2), product structure information (1.3), documents, and the relationships among these three (1.4.1). Geometric and topological information, following STEP AP214, are checked into the CAD database and the feature of the product is defined using the feature-editing system (1.5). The data schema of the CAD database (2.2), feature editing, and the PDM system (2.1) are analyzed to generate nodes in the network and store the relationships among these database (2.3) and thus model the engineering change network. The drag and drop user interface of the ECP modeling module is used to construct (3.1) and link the related node (3.2) and used to define a triggered action (3.3).

When engineering change is implemented, the engineer logs into the PDM system to check out the model of the product and modify the definition of the feature (4.1). The STEP-based interface of the CAD system then calls the ECP system to check the existence of the ECP network (4.2). Finally, the ECP system infers the directed engineering change network and triggers the related task to change the information in the CAD or PDM system.

4.3 Engineering Change Propagation for Sample Assembly

The sample assembly with two plates and one socket screw is investigated to verify validity of the proposed system. An engineering change to the screw is requested by manufacturing engineering and implemented by the product's designer. The diameter of the screw is to change from 20 mm (M20) to 24 mm (M24) to satisfy the stress requirements determined in vibration analyses. The designer opens the model whose ECP network is defined and stored in the ECP system in the CAD system, and changes the diameter parameter of the screw. When the change is committed, the related data items of the CAD and PDM systems in the ECP network are obtained and the sequence of engineering changes are returned by the ECP engine.

Five procedures in ECP modeling are applied to the sample assembly. In this view, the part, product and assembly definition are integrated with the data models of these two systems. The model offers an overall view of the various information systems but does not suffice for engineering change propagation. Entity and instance levels are required to enable engineering change propagation.

The expansion of the entity level can help users to navigate data models and relevant relationship

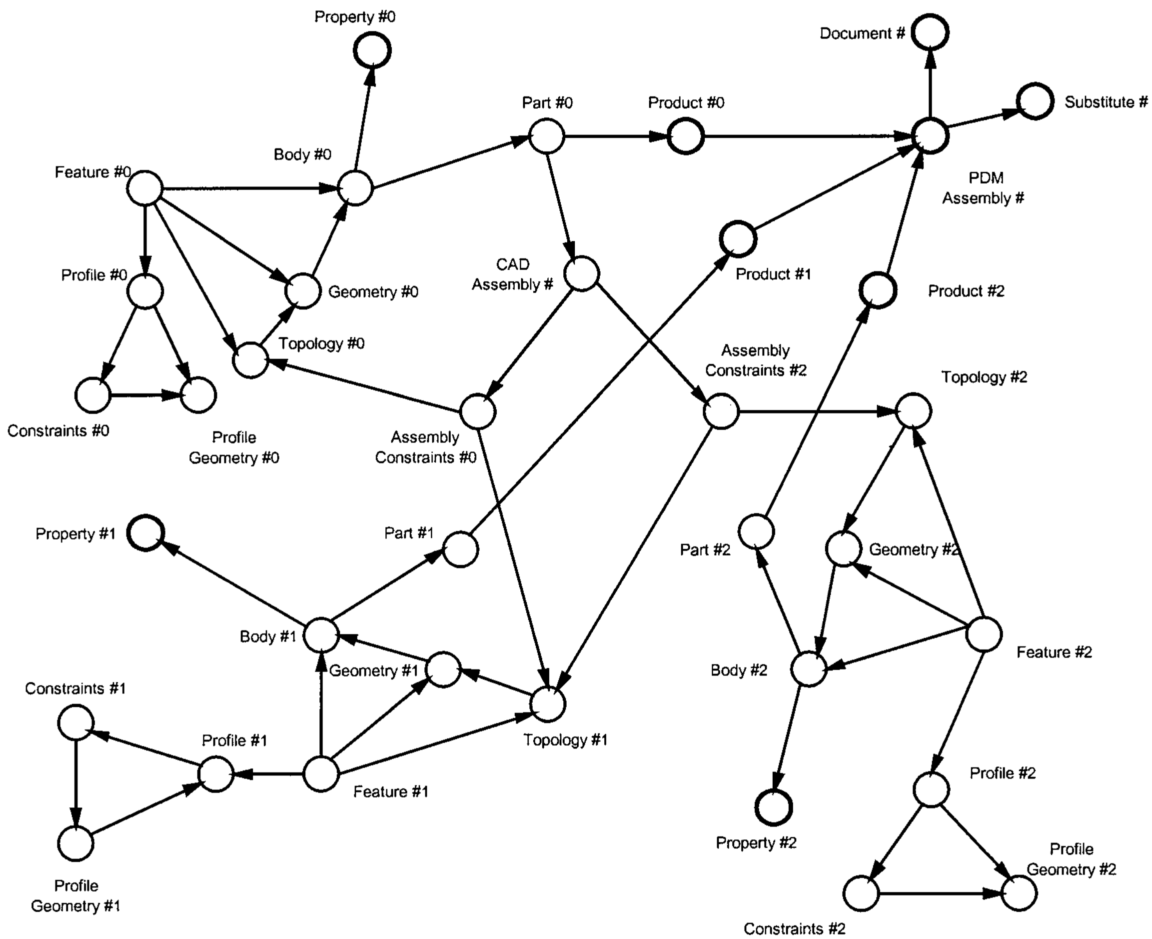


Figure 6. Instance level ECP modeling of CAD and PDM systems.

associations. Instance level modeling is required to enable engineering change propagation since an entity will instantiate various data objects. The instance level model is the major model and includes the ECP network that involves various systems. This level relies on a database manager, CADDBManager and PDMDBManager, to extract data models and associations. Figure 6 illustrates the ECP networks of the sample assembly considered in this paper. The bolder circles represent data nodes in the PDM system; thin circles represent data nodes in the CAD system, and links between the nodes represent possible propagation paths.

Figure 7 illustrates the numbered instances and data relationships of the sample assembly. The data relationships help the ECP system to integrate virtually different systems with different databases. The ECP system will automatically number each data node when inferring engineering change sequence. Users can define the path and direction of the engineering change propagation with the help of association and aggregation of data models, such as STEP EXPRESS models, or data schema of the database. Data defined in the same way in different systems should be combined as a node for engineering change propagation. Consider node 5, a part definition in the CAD system, and node 8, a product definition in the PDM system, for example: both nodes have the same meaning and are replaced by a node numbered $5'$.

When users change the parameter of the screw following an engineering change issued, the constraints defined in the CAD system change the relevant parameters of features and CADDBManager triggers ECPDBManager to obtain the ECP network and search for the related data items using the object identifier of the parameter. Topological ordering is used as the inferring engine to infer the sequence of the engineering propagation paths in the ECP system. The sequence of changed items is, 1, 26, 3, 4, 7, 16, 10, 22, 2, $5'(=5,8)$, 25, 6. The ECP system then sequentially triggers processing rules for each data node. The ECP system will then update data in various databases, showing dialog to allow users to alter attributes, and send notification to the appropriate engineers. The proposed system enables engineering changes to parameters, geometry, specification, operation, manufacturing, document and configuration of screw, slot and assembly in the CAD and PDM systems.

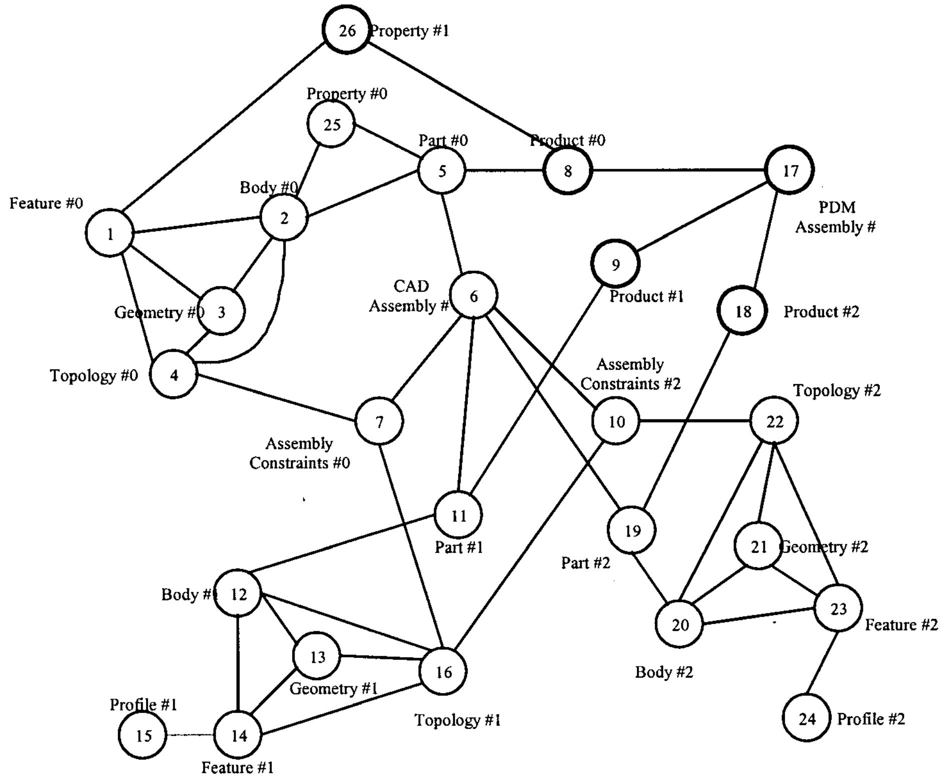


Figure 7. Data association of the sample assembly.

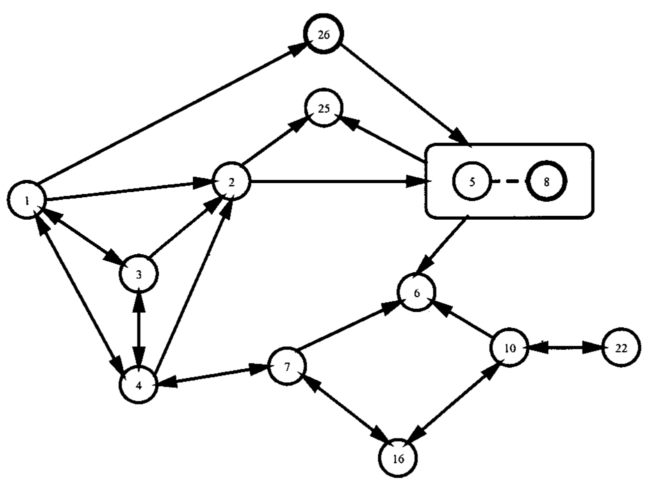


Figure 8. Directed ECP network.

The inferred sequence (1, 26, 3, 4, 7, 16, 10, 22, 2, 5′, 25, 6) is followed to propagate engineering change. Following the defined rule in these nodes, engineering changes will propagate to the affected items in the CAD and PDM systems in turn. The ECP network, shown in Figure 8, causes the engineering change in feature#0 first to change property#1 in the PDM system and then to change the attributes of Body#0, such as volume and gravity center. The processing rules of topology#0 information (node 4), assembly constraint#0 (node 7), (node 16), (node 10), (node 22), (node 2), (node 5′), (node 25), (node 6) will then be executed consecutively to enable engineering changes. Users can define a complicated engineering change rule since the processing rule flexibly defines parallel and sequential procedures.

5. Conclusion

The effectiveness of ECP system proposed here is confirmed by the engineering change propagation of the sample assembly. The system is now implemented in an enterprise, Lioho, in manufacturing industry in Taiwan. The engineering change process can be greatly shortened by applying the system. The system and related STEP-based interface of CAD, feature editing, and PDM systems, allow the engineering change process to be shortened, the number of engineers involved to be reduced, and system operations to be reduced, while protecting against the loss of changed items. The engineering change propagation mechanism can be also applied to integrate various information systems in enterprises to construct a flexible and virtually integrated framework by connecting distributed databases of those systems.

The engineering change propagation system developed here can deal with concurrent engineering change issues in various CAD and PDM systems. A STEP-based modeling capability with ODBC mechanism ensure that the system can manage engineering change among all of an enterprise's information systems, including CAPP, CAM, ERP, PDM, and others. The ECP network in the ECP system proposed in this paper can be used to implement engineering change and immediately advise engineers. The development of the STEP-based manipulation interface is an important part of ECP network modeling and propagation. Meta-modeling and ECP networks of various information systems can be applied to enable engineering change propagation and reduce the time required for engineering change in a product's life cycle. The ECP system can allow an enterprise to integrate various information systems while enabling collaborative engineering using a virtual framework to promote competitiveness.

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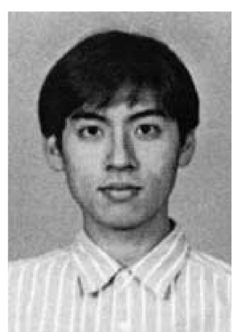

Shen-Chou Yeh received his Ph.D. degree in Mechanical Engineering from NTU. He is working in the area of product data exchange, sharing, and management using STEP. His research interest is in the enabling technologies for STEP-based information system, such as PDM, CAD/CAM, and Collaboration Platform.