AN INTELLIGENT DESIGN RETRIEVAL SYSTEM FOR

MODULE-BASED PRODUCT

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ABSTRACT

The manufacturing industry has shifted its approach from traditional manufacturing to agile manufacturing. The production of customized products will increase in response to the individual demands of customers. In exploring various industry trends, researchers have developed different approaches to designing structural products. The most popular and most commonly used approach in contending with structural products is the modularity approach. Moreover, there are several studies that address modularity with respect to structural representations. Even so, there is not yet a unified method for supporting product structure development and for integrating information. Another aspect that current research has not yet adequately addressed is product information retrieval. Those studies that did contend with product information retrieval, addressed one-level retrieval models, while ignoring structural products. Thus, limitations persist in current intelligent retrieval systems. To answer the aforementioned difficulty, a unified indexing scheme is introduced. In this study, the information can be put into numerical form as the proposed unified indexing scheme, which is represented by a component and structure matrix. The component and structure matrix is the way to achieve an application of modular design retrieval because (1) it is a unique presentation of a structural product and provides a uniform representation; and (2) it lists all modules, as well as all components, in one representation. As a result of the proposed method, an intelligent retrieval system will give an enterprise the ability to communicate with its partners efficiently. Therefore, the aim of this research is to develop a system that will enable more efficient and more effective product-design retrieval systems for structural products, and to demonstrate this framework through a Web-based application using Web technology. To obtain reference designs after utilizing the unified indexing scheme, a Fuzzy-ART neural network is implemented in order to handle retrieval tasks.

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CHAPTER 1

INTRODUCTION

1.1. Introduction and background

New economies and markets recently changed business practices resulting in a new generation of empowered customers who can buy from markets scattered across the globe. Customers play a major role in this new environment, in which companies' success is based upon their abilities to respond quickly to changing customer demands and to utilize new technological innovation. Moreover, companies need to develop new methods and techniques to react rapidly to required changes in products and market trends and to shorten the product development cycle. The manufacturing industry has modified and shifted its approach from traditional manufacturing to agile manufacturing. An agile firm should be able to adjust to new market environments in a timely manner. Throughout manufacturing history, there has been a demand for a firm to deliver high quality products at a low cost. With having agility, it allows manufacturing products to be constructed under high customization environment and at the same time keep cost of production low.

1.2. Product design development

The introduction of a new product into a manufacturing environment is a major expense for a company. A new product design costs a company much money, as do the processes associated with it, such as process planning, production scheduling, and so on. With the increasing worldwide market and the gradually more-competitive manufacturing environment, a new product designs need to be developed with shorter lead-times and better overall performance.

A company may have manufactured thousands of different products or parts in a certain environment. Without being realized that they working on previous designs, designers may work on similar products repeatedly throughout the entire process. It is estimated that 70% to 85% of the life-cycle cost of a product is determined during the early design process (De Fazio, *et al*.1993; Seo, *et al*. 2002). There have been many attempts to assemble models of the design development in systematic structure (Suh, 1990).

Conventionally, a new product is completed through integrating the efforts of design teams in several design stages, and by utilizing all aspects of knowledge from various sources. With the increase of complicated products and the need for a short product-design development cycle, a designer now has to efficiently develop a new design in the shortest time, at the lowest cost and of the highest quality. Instead of following convention, designers realize that modifying or reusing existing comparable designs can significantly decrease the process time and cost (Chang and Tsai, 1997; Smith, *et al*. 1997; Xue and Dong, 1997; Billo, 1998). Design retrieval systems, or automatic systems, have been developed to perform these tedious tasks. With design retrieval systems, similar designs for a new product can be retrieved instantly and effectively. The benefits of selecting an existing component include the minimization of investment, exploitation of economies of scales and the preservation of organizational focus. In contrast to, creating a new design involves more investment in design and production, such as design, prototype, testing and tooling (Ulrich and Ellison, 1999).

Stimulating new product design development, while also responding to customer needs, is a key to a successful marketing strategy. In evaluating marketing strategy, mass customization has become an increasingly important issue for corporations. In addition, the demand for customized products will increase dramatically in the future in response to the individual customer. In order to meet customer demands and achieve high customer satisfaction, manufacturers, suppliers and retailers must base their interactions on a common database and must maintain an exchange of information. Embracing the approach of database sharing and exchange of information enables the entire enterprise to expedite orders and to ensure prompt delivery of goods.

1.3. Mass customization

Developing a product with respect to mass customization has been widely recognized in many areas. Today's products have a highly complicated systematic structure, in regard to function and physical unit. The product structure, as well as the product varieties, needs to be addressed as a new challenge to designers. Modular architecture is an approach that can meet these challenges (Ulrich, 1995).

Modular architecture increases flexibility in design and manufacturing view point in terms of interchangeable components and easy maintenance. Designers or manufacturers can simultaneously work on sub-products or components of products, separately and independently. Developing a new modular product requires a full understanding of customer requirements, as well as abilities and resources of a company. Understanding the interdependencies between customer and product characteristics and properties, and what to reuse and what to replace, becomes key information.

In structural product development, there are many different ways to define a module. The problem arises when a user tries to define a module on his or her own. Many approaches for classifying a system or a product into modules have been developed in order to reduce system complexity (Suh 1990; Huang and Kusiak, 1998; Mikkola and Gassman, 2003). Many researchers have attempted to characterize how to define product information for product modeling. Users may define a finished product several different ways. The difficulty still remains: how we are to respond and retrieve similar products based on different user definitions of modules. The development of a model that is able to support the definition of the product module has been a continuous need (Du, Jiao and Tseng, 2000) since last decade.

1.4. Modular and structural products

Researchers have revealed different approaches in responding to mass customization and structural products. However, the most popular and commonly used approach in contending with structural products and mass customization is the modularity approach. The modularity approach is a concept that has been proven useful in an extensive range of fields that include complex systems. Moreover, modularity is a particular design structure in which parameters and tasks are interdependent within units (modules) as well as independent across each other. A benefit of using modularity is that it increases the range of manageable complexity, in that it allows for different components of a large design to be addressed simultaneously.

Modularity has been described in many ways, depending on the perspective of the analysis. Some define modularization as a process for building a complex product or as a process for creating smaller subsystems that can be designed independently, yet function together as a whole. Modular technologies are effective in improving the speed and reducing the cost of developing new manufacturing products.

Generally, the basic idea of modular design is to organize and structure a complex system, product or process as a set of distinct components or subsystems that can be developed independently and then plugged together. Baldwin and Clark (2000) defined modularity as an approach for organizing complex products and processes efficiently by decomposing complex tasks into individual simpler parts. Modularity gives firms the ability to produce components independently and separately. Thus, modular architectures are built from independent components or modules.

As stated above, modular product development is increasingly becoming a focus of attention and has become a major goal of good design practice. However, it has not received sufficient attention in the literature (Huang 2000). Kusiak and Huang (1996) developed a methodology for determining modular products while considering cost and performance. The module definition can also be thought as mapping between functional requirement (FRs) and design parameters (DP) (Ulrich, 1995; Suh, 1998). Huang and Kusiak (1998) developed models and approaches to solve the modularity problem for mechanical, electrical and mixed process products (e.g., electro-mechanical products).

A modular product also can be thought of in functional and physical terms. The functional terms of a product are the individual processes, operations and transformations that yield the overall performance of the product. The physical terms of a product are the parts, components, and subassemblies that ultimately deliver the product functions. The physical terms of a product are organized into several building blocks. Each block is a collection of components that implement some functions of the product. A block may be a collection of interchangeable components that implement similar functions, in which case the block is called a module as shown in Figure 1.1.

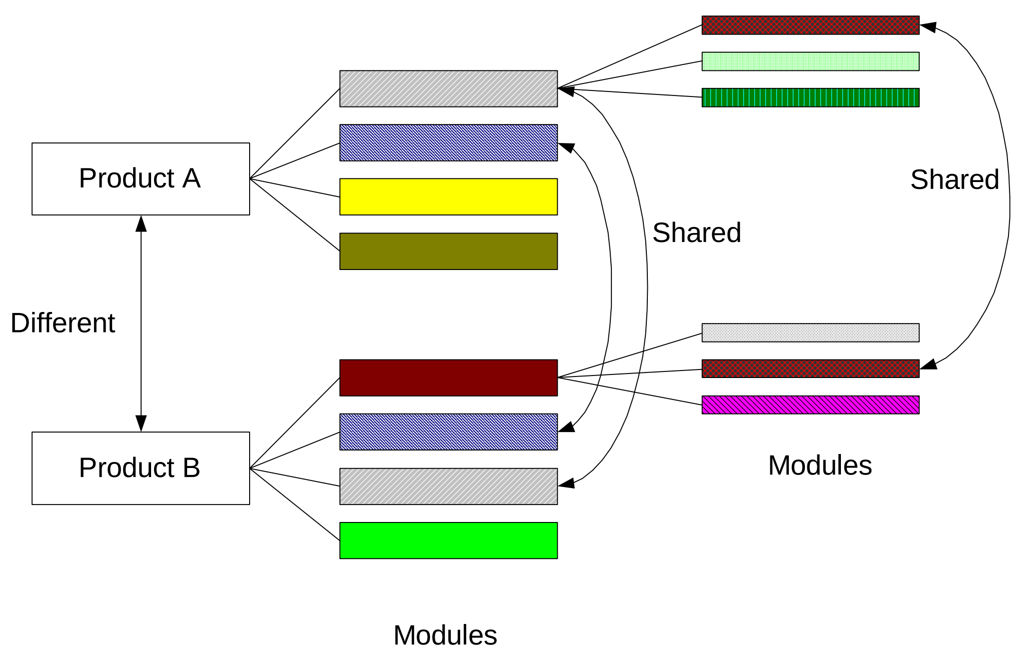


Figure 1.1. Modular product structures

One advantage of modularity is its ability to accommodate uncertainty. It allows flexibility in designs and structures. Thus, it follows that it would be simple to incorporate a new solution without changing much in the system, if new knowledge provides a better solution for one of the hidden module designs (Baldwin and Clark, 2000). The benefits of modularity implementation include (Kusiak and Huang 1996): (1) economy of scale; (2) increased product variety; (3) reduced order lead time; (4) increased feasibility of component change; and (5) easier product maintenance and repair.

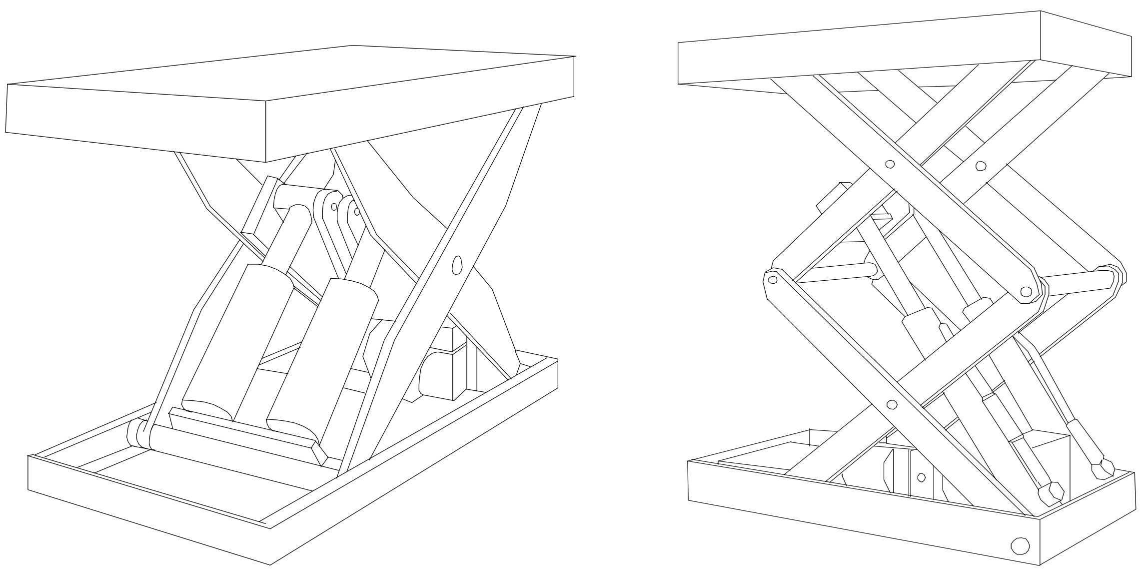


Figure 1.2. Sample of modular products

Modularity increases the range of manageable complexity, in that it confines the range of interaction between elements or tasks, and thus decreases the amount and range of cycling that occurs in a design or production process. Moreover, as the number of steps in an interrelated process increases, the process becomes increasingly difficult to successfully complete. Thus, by confining the set of possible interactions, modularity reduces the range and scope of potential cycles, which in turn, make successful completion more possible.

However, producing large customized systems can be very costly for the proliferation and maintenance of new parts design (Smith, Escobedo, Anderson and Caudell, 1997). A designer who begins the task of developing a new conceptual design must either start from zero or obtain an existing drawing from current files, which he then modifies in order to satisfy the new part requirements. One way to expedite product development is to retrieve information from the database. After extracting the necessary information from a database, the information can then be modified according to the customer's needs and demands. In order to establish a structure database retrieval system, one fundamental issue needs to be addressed: the module representation for its functionalities, parameters, and interfaces.

1.5. Design indexing and retrieving methods

In order to develop new products that reflect the customization movement, the modularity approach needs to be implemented. More specifically, modular products are one of the essential aspects of agile manufacturing, which ensure variability in products that fulfill potentially diverse customer requirements. As mentioned in the previous section, one method to accelerate product development is to retrieve information from a database and then modify according to the customer's needs and demands.

An information retrieval system contends with the representing, organizing and accessing to information items. In the past 20 years, the field of information retrieval has gone well beyond its primary goals of indexing text and searching for documents in a collection (Baeza-Yate and Ribeiro-Neto, 1999). A user of a retrieval system has to translate his information need into a query in the language provide by the system for executing a retrieval task.

Once a product database is completely indexed, the retrieval process can then be initiated. The query is processed to retrieve the products. Quick query processing is achievable because an index structure has been created. Before being sent to designers, the retrieved products are ranked according to a likelihood of importance or similarity. The designer then examines the set of ranked products for useful information.

In design databases, indexing and retrieval are related to each other. The selection of an indexing technique for a retrieval system is one of the most important factors in determining the performance of the system. Indexing data for a database can significantly influence the way in which information can be retrieved (Bhatta and Goel 1996). The designer specifies both the attributes of the product that define the search and the required level of similarity for each attribute. These attributes correspond to those of the product indexing schemes. This process can be manually or automatically undertaken to create a direct search in a database or an indirect search via index files. Also, consider that the conceptual design is an extensive and unlimited information-processing task for a designer. Thus, the designer uses the design retrieval method to retrieve a known design that is similar to the new conceptual design problem, and uses that information while working to solve the problem. The method also gives the designer the ability to retrieve the reference designs when a new query is specified

Many part-based indexing schemes have been developed for design retrieval systems, with categories such as manufacturing processes, geometry, features, machining operations, and material used. In most of the design retrieval systems that have been developed, Group Technology (GT) has been widely used as the data indexing technique.

However, indexing values must be recoded from time to time, because information is often embedded in its geometric and topological descriptions instead of derived from a fixed GT code (Chang and Tsai 1997). The problem of finding a similar design is time consuming and much effort is spent with large databases (Dowlatshahi and Nagaraj, 1998). Many retrieval strategies such as Boolean models, vector models, fuzzy models, proximity, and contiguous word have been proposed to achieve these objectives (Kim and Kwang, 2001). Once the retrieval strategy is provided, techniques such as similarity measures, ranking and relevance feedback are implemented to obtain relevant information. Although information retrieval techniques are widely successful in a variety of applications, a limitation still exists in design retrieval.

The use of classic information retrieval methods has given us further problems due to the differences in the data format that is handled within the retrieval systems and retrieval techniques that are incompatible with product designs. More specially, the use of text or words in traditional retrieval systems may be problematic because due to the complexity of the product structure and components. Currently, Boolean logic is the most-used search mechanism for information retrieval systems (Cortez, Park and Kim., 1995). The Boolean-based information retrieval system retrieves all the relevant information that matches the query exactly. Thus, the Boolean-based information retrieval system discards all non-matches or partial matches and only includes exact matches in the query. A product design development, however, inclusion of non-matches and partial matches, in addition to the exact matches.

Traditionally, a search scans product databases of the candidate manufacturing partners and reads each database. The procedure then compares the values of the new query in the database with values for each selected attribute. Thus, if all of the scrutinized databases fall into the target ranges, the search retrieves products similar to the design under consideration.

Using an artificial intelligence technique provides paradigms for the use of experiential knowledge in memory to aid in the solution of problems and the performance of tasks. Because of this technique, artificial intelligence research is a good candidate for a support system in design problem solving. For an example, a design retrieval system using ART1 neural network is implemented to retrieve reference designs by controlling the similarity threshold, and vigilance parameter (Chang and Tsai, 1997; Smith, Escobedo, Anderson and Caudell, 1997). This technique helps a designer to decide how many references that they want to see.

1.6. Web-based information retrieval

Currently, areas of information and communication technology have focused on the increase in speed of technological change and turbulence of competitive environments, the emergence of a positive feedback industry and the increasing importance of standard and technology platform competition (Keil, *et al*. 2000). The need of an Internet-based information system framework is essential. An enterprise strongly looks for an effective tool to manage and manipulate the flow of information among participating businesses. The design and implementation, which has the capability to adjust to the ever-changing interactions among businesses in a mass-customization environment become more and more necessary.

Moreover, global wide enterprises are become common in the manufacturing industry. With shorter developing and manufacturing lead-times, the competitiveness and profitability of an enterprise can be tremendously increased with an international presence. Everyday operations will be automated. A global information network will be connected in the near future. Competitive manufacturing organizations that information connected and knowledge driven have become widely accepted in as leader in the manufacturing environment.

With the great technology of the Internet and the World Wide Web, a variety of Web-based applications have been developed and implemented in product design and manufacturing (Cheng, Pan and Harrison, 2001, Huang and Mak, 2001b); yet more will become available in the very near future (Huang and Mak, 2001a). Many who work in product design and manufacturing have shifted to Web-based environments such as a

Web-based manufacturing service system for rapid prototyping (Lan, *et al*. 2004), a Web-based search system of pattern recognition (Hsiao, Sung and Ou, 2004), a Web-based bearing design support system (Cheng, Pan and Harrison, 2001), and remote robot manufacturing (Wang, Chu and Yin, 2001). As one can see from efforts in these Web-based applications, Web technology is accepted as a highly adequate information infrastructure for providing collaboration among organizations.

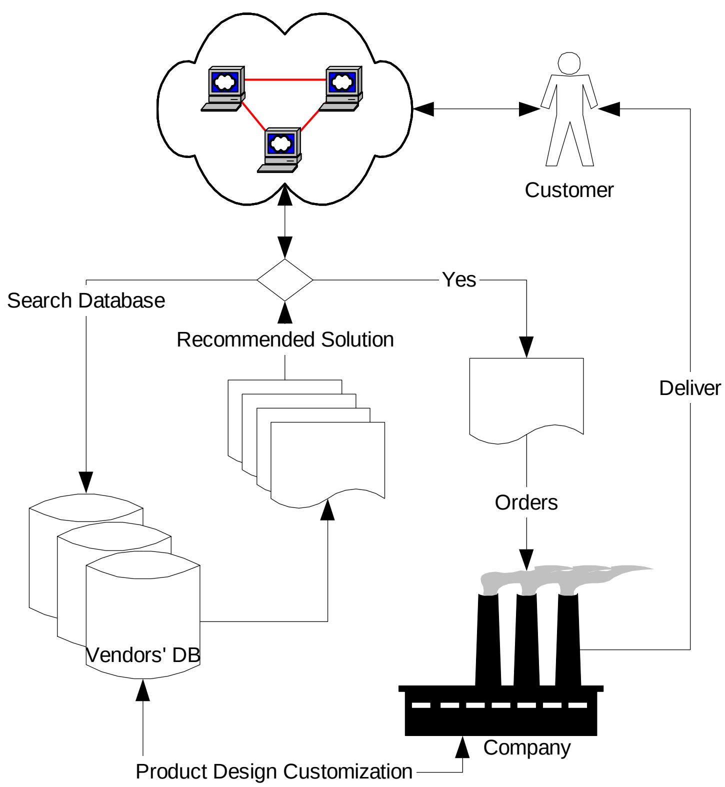


Figure 1.3. Web-based ordering system

As a result, Web-based application has become a new highway of communication among customers and enterprises in manufacturing environments. It enables agile manufacturers to promptly communicate with customer demands by eliminating integration barriers. Customers are now able to rapidly customize their product via web-based applications. Past studies have covered several main areas of Web applications. However, to support the utilization of Web applications in product design and manufacturing, manufacturing-specific search engines are still awaited. Regardless of efforts made in developing Web applications, and despite the early promises of Web-based technology, the Web-based approach is still far from being widely accepted (Huang and Mak, 2001a).

1.7. Organization of the research

This dissertation is arranged as follows. Chapter 2 reviews, in detail, the related literature that supports this study. The chapter includes various design indexing methods, and various algorithms used in design retrieval systems. Modular product design tools and Web-based technology in product design and manufacturing are also reviewed. Based on the reviews of the publications problems of current design retrieval systems are stated and clarified. Then, the major research objectives of this dissertation are depicted. Chapter 3 introduces the technical background associated with the proposed unified indexing scheme for databases. The next assembly quantity matrix and the total requirement factor matrix are utilized. The proposed unified indexing scheme is developed. The Fuzzy Adaptive Resonance Theory (Fuzzy-ART) neural network utilization is exclusively discussed in detail and used as retrieval mechanism. Then, the structural database conversion is utilized.

In Chapter 4, the implementation of the proposed method is carried out as part of a modular product design retrieval system and present to web-based environment. Web-based modular product retrieval system is used as a company representative for users to make a query for a new conceptual design.

In conclusion, Chapter 5 summarizes this study. Its significant contributions are pointed out. Comparisons with current design retrieval systems are provided to show the benefit of the proposed system. Lastly, further research is considered.

CHAPTER 2

REVIEW OF LITERATURE AND RESEARCH OBJECTIVES

2.1. Overview

The development of a new product design environment is not difficult to understand or complicated to implement. The need to increase overall performance in the design process makes the retrieval of reference designs attractive to many researchers, because it takes less time to construct a new product design when an existing design is modified. In recent years, a number of techniques have been developed and implemented to improve the ability of a computer-aided system in supporting the design process. In this chapter, different approaches to product design indexing and retrieval are described in order to highlight significant aspects regarding new product design development. In addition, recent investigations of developments in product architecture and mass customization are reviewed in the areas of design, retrieval and effective use of organizational resources. Manufacturing and the proficient use of organizational resources require an extensive understanding of how to use and expand resources for creating various products for individual needs. Moreover, a comprehensive research agenda, which explores the impact of information and communication technology on selected manufacturing fields, has been investigated

With a modular product approach, components can be disassembled and recombined into new configurations. This approach provides manufacturers with a lot of opportunities to respond to customer needs. The chapter also covers the module definition and modular design. Thus, recently developed studies, topics relevant to the scope of this study, and detailed information are reviewed. Later in this chapter, problem statements are determined, and research objectives are specified.

2.2. Design indexing techniques

To expedite product development, one solution is to retrieve information from a database. After extracting the necessary information from a database, the designer can then modify the information according to the customer's needs and demands. The designer specifies both the attributes of the product that define the search and the required level of similarity for each attribute. These attributes correspond to those of the product indexing schemes. This process can be manually or automatically undertaken to create a direct search in a database or an indirect search via index files. The problem of identifying a similar design is difficult and is a time-consuming effort with a very large-scale database (Dowlatshahi and Nagaraj, 1998). Regardless of which methods or structures are adopted the core factor determining failure or success of the product is design indexing. Without an efficient support of resources, any developing mechanism is invalid (Zhou, *et al*. 2003).

In a very large database that supports computer-aided collaborative designs, a proper indexing scheme is crucial when the retrieval process involves selecting a group of reference designs from many possibilities. The ability and efficiency of a retrieval system in a database system depends on indexing technique (Ahmad and Grosky, 2003).

Traditionally, indexing methods for components and manufacturing products can be classified as group technology coding, feature-based representation, image content-based representation, and others.

Group technology (GT) is a manufacturing scheme in which components or products similar in material, in manufacturing process, or in geometry are grouped together in order to take advantage of their similarities in manufacturing and design processes. The GT-based indexing approach is broadly implemented for the retrieval task. Using GT coding is useful for the efficient retrieval of previous designs and assists in accelerating the design process. A discussion of studies of some recently developed GT indexing schemes follows.

Dowlatshahi and Nagaraj (1998) facilitated the GT idea to reduce design time and efforts by finding a similar design from a database. They developed a classification and coding system called the Interactive Design Retrieval System (IDRS), which boosts the efficiency of design retrieval processes. However, the system also has limitations. The utility of the system is diminished if the data are not standardized. Moreover, the product information is limited by the length of GT codes.

Candadai, Herrmann, and Minis (1996) introduced an Object-Oriented Group Technology (OOGT) scheme to support design indexing and retrieval, variant design, variant process planning, and design critiquing. They then used the model to accomplish an efficient search for similar products manufactured by selected companies and to retrieve and utilize information about the manufacturing processes and the performance of similar products.

Fowler, Cochran, and Horng (1999) have published supporting literature in modeling and simulation of a semiconductor manufacturing database that uses a GT coding of articles based upon index searching. The Modeling and Analysis of Semiconductor Manufacturing Laboratory (MASMLAB) database was developed in order to facilitate speedy searches by problem type, measurement metric, modeling technique, organizational decision level, publication year, and publication type. Moreover, this searchable database has been implemented as an Internet site.

Xue and Dong (1997) developed a design feature (represented as mechanical components and mechanisms) coding system based on design functions analysis. In addition, the researchers developed a manufacturing feature (a geometric element to be produced) coding system based on product geometry and product operations analyses. These two types of features are then coded and organized as clusters using a GT-like approach for generating design references and planning production processes.

Even though a GT indexing scheme works efficiently with the manufacturing process, its use as a design retrieval system still has several problems. The problems include defining main features of designs, a suitable GT coding selection, and part designs encoding. Moreover, indexing must be redefined because design information is often embedded in its geometric and topological descriptions. Although several GT methods are used to describe the geometric and topological information about a part, these methods are limited by the number of digits used in each representation. Using fixed GT code as the design index makes it hard to fulfill this geometric and topological information requirement (Ou-Yang and Liu, 1999).

Another indexing scheme that is known to be effective for a product retrieval system is a feature-based indexing scheme. Feature-based design is a mechanism that allows designers to maintain design objectives, while creating the geometry of the product (De Fazio, *et al*. 1993). Those design objectives are assembly topology, product information, and manufacturing process plan. The feature-mapping process is a central characteristic of feature-based design, also called feature transformation. Through a mapping process, an initial feature model is transformed into a product model comprising features of interest to the downstream reasoning processes. Furthermore, Allada and Anand (1995) have gathered comprehensive reviews on feature-based modeling and feature-recognition methods related to feature mapping processes for product models.

Feature-based design retrieval systems that use a Destructive Solid Geometry (DSG) as an indexing scheme had been developed (Chang and Tsai, 1997, Tsai and Chang, 2003). The DSG coding approach is a scheme that enables users to collect form features of a design in an efficient way. Each part is coded into binary code based on its form features using a different operator.

Ou-Yang and Liu (1999) presented a feature-based CAD file retrieval system. It is an integrated approach to retrieve CAD files by using topological relationships between features as an index scheme. However, their system is inflexible from the user's view because users need to follow queries to do retrieval tasks systematically. Moreover, most industrial products are assembled parts, the need to develop a method to retrieve assembled parts, or composed components still remains.

Ounis and Pasca (1998) presented a system that provides a computer-assisted image indexing process. Conceptual graphs formalism is used as the indexing language, which allows using not only keywords, but also the relations between them. The result of the indexing process, which is a set of conceptual graphs, is then organized to improve retrieval execution times. Their image retrieval system, called RELIEF is executed on an object-oriented database management system using Web-based technology.

Yang (2001) developed a prototypal system for an image retrieval model for indexing and retrieving images with fuzzy triples. The model supports concept-based image retrieval, as well as inexact match with a fuzzy triple matching performed when evaluating queries. The system is implemented in order to eliminate two significant drawbacks in two-dimensional string index mechanism: it cannot accommodate concept-based image retrieval and it does not deal with an inexact match among directions.

Ahmad and Grosky (2003) proposed a symbolic image representation and indexing scheme for a domain independent, spatially similar images support. Their indexing scheme is based on the concept of hierarchical decomposition of an image into a spatial arrangement of distinct features. Their method is to eliminate the repetitive tasks of image understanding and object processing.

Cha and Chung (1998) developed an HG-tree indexing scheme to use in content-based retrieval in an image database. However, only 24 features are employed to categorize the images. As a result, there is also a need for a flexible index structure which supports varying dimensionality. That mean if there are more images added to the database, more features will be needed.

On the other hand, instead of component based retrieval, McAdam, Stone, and Wood (1999) use customer needs data to create functional interdependence for identifying modules for modular architecture. By using a product function matrix, the new conceptual design can be compared to existing product databases based on functional similarity knowledge to select a product for development.

In conclusion, indexing and retrieval are related to each other. The selection of an indexing technique for a retrieval system is one of the most important factors in determining the performance of the system. As one can see from the aforementioned studies, indexing data for a database significantly influences the way in which information can be retrieved. However, the flexibility of indexing still remains an issue in the retrieval system application. There is inflexibility from the user's viewpoint, because users need to follow queries to do retrieval tasks systematically. Several GT methods are limited by the number of digits used in each representation. Additionally, in a feature-based environment, the approach becomes very complex to implement, if there are interacting manufacturing operations or features (Sharma and Gao, 2002). Although these methods are efficient in general retrieval tasks for existing databases, they have major drawbacks when new components are introduced to the conceptual designs (Chang and Tsai, 2001).

2.3. Product design retrieval mechanism

Conventionally, an information retrieval system has the ability to store, retrieve, update, and maintain database information. Moreover, an information retrieval system contends with the representation and organization of, and the access to, information items. A user of a retrieval system has to translate his information need into a query in the language provided by the system for executing a retrieval task.

Lipson and Suh (2000) proposed architecture for a design knowledge, which will provide a substrate for automation in the engineering design process. They also define the components of a design step (knowledge describing, describing undeniable parameters, physical behaviors and interfaces). To solve series of ambiguity and incoherence (with textual, keywords, and symbolic representations), all information is stored in mathematical form. The authors conclude by stating that a more practical design is needed. It is still far from a fully automated conceptual design because designers interfering still occur.

Shah, *et al*. (1996) address the problem of accurately capturing and re-using design history information. Particularly, the authors present a framework through which a combination of findings from computer engineering, data engineering and knowledge engineering give rise to an environment for the capture and reuse of design history. Design process representations are combined with enhanced STEP models, which are then translated into data definition language in order to perform operations on an object-oriented database. The authors conclude by outlining the many benefits of reusing design history information. The authors also conclude that a comprehensive development of design history data models will ensure a stable framework for incorporating design environments with adequate support for design history capture and reuse.

Once a product database is completely given a query, the retrieval process can be initiated. Before being sent to designers, the retrieved products are ranked according to a likelihood of importance or similarity. The designer then examines the set of ranked products for useful information.

Retrieval strategies such as Boolean models, vector models, fuzzy models, proximity, and contiguous word have been proposed to achieve these objectives (Kim and Kwang, 2001). Once the retrieval strategy is provided, techniques such as similarity measures, ranking, and relevance feedback are implemented to obtain relevant information.

Wan, Hu and Shi (2001) proposed an image similarity measurement of a content-based image retrieval system by using maximum weighted bipartite matching. The retrieval system consists of two stages: First, they parted images based on perceptual color homogeneity, color regions, texture, scale, location, and shape characteristics to represent the content of regions. Second, a maximum weighted bipartite matching scheme was used to measure the similarity between images. The matching between images can be represented by a weighted bipartite graph in which every vertex corresponds to a region and the distance between regions are represented by a weighted edge as shown in Figure 2.1 below:

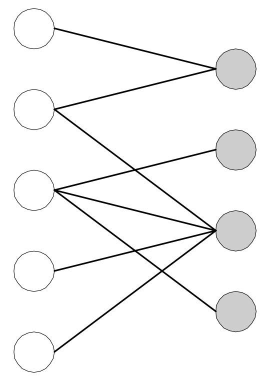


Figure 2.1. Maximum weighted bipartite matching scheme

The similarity between two images are then calculated and it is determined whether or not the images match. As is well known, this problem can be stated as the following linear programming problem (Carraresi and Sodini, 1986):

$$\text{Max} \quad \sum_{i \in I(j)} \sum_{j \in J(i)} x_{ij} \tag{2.1}$$

$$\text{s.t.} \quad \sum_{j \in J(i)} x_{ij} = 1 \quad , \quad i = 1, \ldots, n \tag{2.2}$$

$$\sum_{i \in I(j)} x_{ij} = 1 \quad , \quad j = n+1, \ldots, 2n \tag{2.3}$$

$$x_{ij} \quad \geq 0 \quad (i,j) \in V,$$

where $j(i) \quad = \quad \{ j \in R: (i,j) \in V \}$

$i(j) \quad = \quad \{ i \in L: (i,j) \in V \}$

The exercise of finding maximum matching in a bipartite graph has many practical applications. As an example, we might consider matching a set L of machines with a set *R* of tasks to be performed simultaneously. A maximum matching approach provides work for as many machines as possible at a given time.

McSherry (2002) discusses case-base reasoning, which is considered a retrieval method. The author proposed a system to help users in selecting available product that are most similar to a target query representing the elicited requirements of the user. McSherry claims that nearest neighbor retrieval algorithm can be generalized to support much more flexible queries, in which a user can specify any number of preferred values of selected attributes.

Suzuki, Wang and Ikeda (2002) proposed the retrieval of industrial products using a sketched image drawn by the designer of the basis of artistic industry design as a new type of expert system. The method is applied to the artistic design of various industrial products. Their image retrieval system has a success rate of 75%-85% in their study.

Similarly, Funkhouser, Min, Kazhdan, Chen, Halderman, Dobkin and Jacobs (2003) develop a shape-based search system. They present a web-based search engine system that supports queries based on 3D sketches, 2D sketches, 3D models, and/or text keywords. Moreover, they have developed a new matching algorithm for the shape-based queries. The key challenges are to develop query methods simple enough for beginners and matching algorithms robust enough to work for arbitrary polygonal models. In summary, the study investigates issues in building a search engine for 3D models. However, structural products are not yet considered because the method is only based on shape information and text information.

Agrawal and Srikant (2003) proposed an approach that does not require an accurate correspondence between values and their names when searching among specification documents. Successful searches can be accomplished despite omissions of names or the lack of attribute names. The authors outline indexing structures and algorithms, as well as hints from automatic data extraction techniques, which, when combined with the proposed approach yields higher accuracy in high reflectivity data sets.

Classic information retrieval techniques are known to be incompatible with design retrieval (Chang and Tsai, 2001). Specifically, product components and product structures are difficult to represent in words, due to the inherent complexity of the product structure. For example, Boolean-based information retrieval accepts only exact matches, while excluding partial or non-matches of the query. However, product design development not only requires the inclusion of exact matches to a query, but also the inclusion of partial matches.

Tsai, Tien and Pan (2004), discuss the development of an XML-based product retrieval system for virtual enterprises. In their article, the authors represent a structural product as a rooted tree, where each vertex of the tree is a product component. Specifically, the authors suggest that a component can be composed of one or more modes. In addition, each of the modes belong to the same component and are considered similar in functions, with only minor differences. Tsai, Tien and Pan also introduce two types of structural similarities, which are *configuration similarities* and *mode similarities.* The authors also compare a series of strings, which are created from the rooted tree matrices between a query and a database. These strings are used for structural similarity measurements. Their matching algorithms are developed from a traditional edit distance evaluation.

Content-based retrieval is also used where multimedia databases are available. However, Wang *et al*. (2003) mention that most content-based retrieval techniques are based on two dimensional information. The authors proposed a similarity method based on three-dimensional information, which is extracted from a Virtual Reality Modeling Language object database. The authors proposed using OCT-tree three dimensional objects representation. Also, a similarity matching score is based on the weighted OCT-tree between each other.

Using an artificial intelligence technique provides paradigms for the use of experiential knowledge in memory to aid in the solution of problems and the performance of tasks. Because of this technique, artificial intelligence research is a good candidate for a support system in design problem solving. The most well-liked preference in information retrieval is implementation of neural networks. A neural network provides information processing structure attributes for adaptation to fulfill the needs within an information environment. For example, neural networks are easily adapted although the submitted queries are not exact in nature. Neural networks can be used as a tool in research. There have been several artificial neural networks applied for design retrieval system.

There are several groups that use neural networks as their retrieval mechanism to identify similar designs. In batch manufacturing systems, retrieval of old designs that meet current requirements on geometrical or technical information is a common problem. Venugopal and Narendran, (1992) used the Hopfield net model as a mechanism to develop a design retrieval system. The authors verified the Hopfield net model with test cases on rotational as well as non-rotational parts.

Similarly, Smith, Escobedo, Anderson, and Caudell (1997) used two-dimensional and three-dimensional representations of engineering designs as input to an adaptive resonance theory (ART1) neural network to produce clusters of similar parts. All design queries were fed into the ART1 neural network to build a proper group of product families by controlling a similarity threshold as well as the vigilance parameter. Also this system—a neural information retrieval system (NIRS)—can create new groups when parts fail to match any current grouping instances. An appropriate cluster is recalled when a query with a new part design is made to the trained network.

Tsai and Chang (2003) proposed an intelligent design retrieval system involving soft computing techniques for both feature and object association functions. A feature association method that utilizes fuzzy relation and fuzzy composition was developed to increase the searching spectrum. In the mean time, object association functions composed by a fuzzy neural network allow designers to control the similarity of retrieved designs. Their implementation result shows that the intelligent design retrieval system with two soft-computing-based association functions can retrieve target reference designs as expected.

Moreover, several Fuzzy-ART neural network application literatures present its usefulness and effectiveness as a retrieval mechanism. Araújo and Almeida, (1998) implemented Fuzzy-ART neural network architecture for online map building based on geometric primitives. Park (2000) used Fuzzy-ART in customer clustering based on the customer's purchasing history in e-commerce.

2.4. Module-based product modeling

Today's products have a highly complicated systematic structure, in regard to function and physical unit. Developing a product with respect to mass customization has been widely recognized in many areas. Modularity provides the agility of manufacturing system. It allows products to be manufactured in a high customization environment, and at the same time, keep development time low (Khoo and Situmdrang, 2003). There have been attempts to address various issues. Many researchers have attempted to systematically characterize product information for product modeling (Suh 1998; Huang and Kusiak, 1998; Mikkola, 2003; Du, Jiao and Tseng, 2000). Fujita, Sakaguchi and Akagi (1999) presented the possibilities of design optimization for product variety under fixed product architecture. The studies associated with modularity can be categorized into two areas: modular design and module identifications. They are discussed as follows:

Design with modules has been widely studied in the field of modularity. In a challenge to mass customization, the purpose was to make varied and customized products at the cost of standardized, mass-produced goods. The design of the assembly system to produce modular product also has been discussed (He and Kusiak, 1997). Through modularity, the number of parts to be produced for a product family is reduced significantly, while the manufacturer can achieve high variety by combining different modules in different ways. Because of variety of products, there are numerous ways to define a module combination.

Similarly, Chakravarty and Balakrishnan, (2000) presented how the choice of module-options affects product variety, module-option commonality, total sales, product development cost, and company's profit. As rank ordered module-option, they based on their profit margin, customer rating, and development costs.

Huang and Kusiak (1996) developed models and approaches to solve the modularity problem for machining-assembly system. The performance of the models is measured by the makespan of an aggregate manufacturing system scheduling. They developed design rules in order to improve the performance of manufacturing systems.

Yigit, Ulsoy, and Allahverdi (2002) addressed the problem of optimizing modular products in a reconfigurable manufacturing system. They developed the optimizing model based on finding a trade-off between the quality loss due to modularity and the cost of reconfiguration. Then their method was implemented and used as a systematic tool in selection of module instances.

Gonzales-Zugasti and Otto (2000) proposed a general technique for building products onto modular platforms. The platforms allow designers to work with existing and new components. The researchers addressed the problem as an optimization exercise.

Based on the combination between the modules, product modularity can be represented. Combinations between modules are categorized based on the types of interactions between the different modules within a product. Four categories are defined (Kamrani and Salhieh 2000).

Component-swapping modularity: The component-swapping modularity occurs when combining two or more alternative types of components with the same basic component or product in order to create different product variants belonging to the same product family. An example of component-swapping modularity is illustrated by matching different types of optical drive, monitors, and keyboards with the same motherboard. This allows for different models of computers to be implemented.

Component-sharing modularity: Different product variants belonging to different product families are created by combining different modules sharing the same basic component. Component-sharing is considered the complementary case to component-swapping. Component-sharing and component-swapping modularity are identical except that swapping involves the same basic product using different components and sharing involves different basic products using the same component. Component-sharing modularity in the computer industry is represented by the use of same power cord, monitor, or microprocessor in different product (computer) families.

Fabricated-to-Fit Modularity: One or more standard components are used with one or more infinitely variable additional components. Variation is usually associated with physical dimensions that can be modified. A common example of this kind of modularity are cable assemblies in which two standard connectors can be used with an arbitrary length of cable.

Bus Modularity: This type of modularity occurs when a module can be matched with any number of basic components. Bus modularity allows for variation in the number and location of basic components in a product while component-swapping and components-sharing modularity allows only for the types of basic components to vary. An example of bus modularity is a computer where different I/O units such as monitors and keyboards are present as well as different types of mice, RAMs, and hard drives.

Modular architecture increases flexibility, from the design and manufacturing viewpoint, in terms of interchangeable components and easy maintenance. Designers or manufacturers can simultaneously work on sub-products or components of products, separately and independently. Developing a new modular product requires a full understanding of customer requirements, as well as the full abilities and resources of a company. Understanding the interdependencies between customer and product characteristics and properties, and what to reuse and what to replace, becomes key information.

Another modularity issue that needs to be addressed is module identification. There are many different approaches to modularize a product. The problem arises when a user tries to define a module on his or her own. Many approaches for classifying a system or a product into modules have been developed in order to reduce system complexity.

Ulrich (1995) discussed modules and architectures according to the mappings between functions and physical modules as a common principle for approaches based on modularity. He defined product architecture as the arrangement of functional elements, the mapping from functional to physical elements, and the interfaces among interacting physical components.

Likewise, Salhieh and Kamrani (1999) similarly defined decomposition of modularity based on its functional and physical characteristics. They develop a systematic approach to identify components in modules that could be developed in parallel. They determine needs and functional requirements for a new product. The function requirement weights are used to provide a similarity index in order to group components into modules and to offer a product architecture selection based on functional and physical factors. Their approach is to simplify the interactions between components and increase the reusability of the designed components.

Baldwin and Clark (2000) defined modularity as an approach for organizing complex products and processes efficiently by decomposing complex tasks into individual simpler parts. Modularity gives firms the ability to produce components independently and separately. Thus, modular architectures are built from independent components, or modules.

Not only can the modularity concept be viewed as physical components, but it can also be implemented in software components. Feng and Zhang (1998) developed architecture for the rapid development of computer aided process planning (CAPP) systems. The specification of the architecture and its building blocks are defined in order to support the construction of CAPP systems from prepackaged, plug-compatible software components.

Lee and Lee (2001) propose an integrated design system in order to incorporate the representation of the shape of a product with the storage and usage of design information using object-oriented method called Element Object. The authors define Element Object, which can represent a variety of information, including design parameters, documents, catalogs, functions and behaviors. The authors propose that through the use of the system, management of design information and relation could be performed in a systematic manner. They conclude by outlining the benefits of using this system, which include reduction of design time and reduction of errors during initial design and re-design.

However, producing large customized systems can be very costly for the proliferation and maintenance of new parts design (Smith, Escobedo, Anderson and Caudell, 1997). A designer who begins the task of developing a new conceptual design must either start from zero or obtain an existing drawing from current files, which he then modifies in order to satisfy the new part requirements. In addition, modular product development is increasingly becoming a focus of attention and has become a major goal of good design practice. However, it has not received sufficient attention in the literature (Huang 2000). A commonly agreed-upon definition of modules has not been found yet, the main differences being the view of how functionality of a product is realized within a module and how to define a module interface.

2.4.1. Component-based product views

In the past, much research had been conducted on the one-dimensional index basis. Coding product data is, by its nature, hierarchical in structure. However, relational database management systems distribute this hierarchy into a number of flat tables (Billo, 1998). The results of these database systems indicate that the one-dimensional index results in an ineffective search outcome because it is unable to retrieve a similar product at different levels. For example, considering the component table of the following design structure (Figure 2.2):

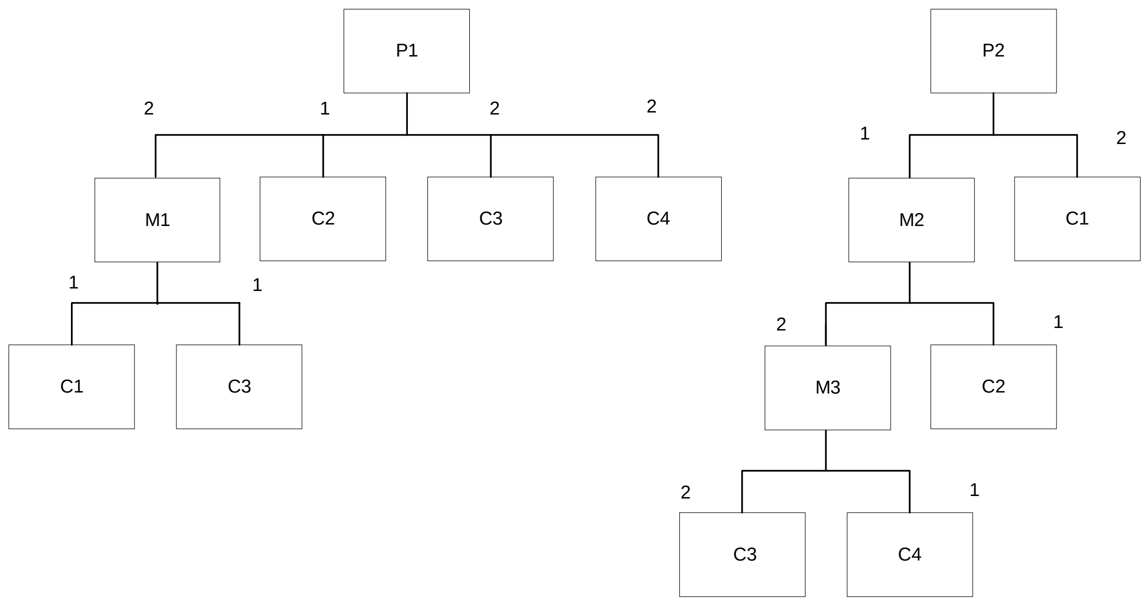


Figure 2.2. Examples of alternative product structure

As we can see from Figure 2.2, P_1 and P_2 component structures are different. However, their components are the same as shown in the Table 2.1. This results in ineffective search outcomes.

	C1	C2	C3	C4
P1	2	1	4	2
P2	2	1	4	2

Table 2.1. P1 and P2 product components

Principally, component-based retrieval is not effective. We still need a method that can retrieve both structure and component.

2.4.2 Structure and module-based product view

Several studies have identified or defined the meaning of modular products. The term *modularity* is frequently used to define the use of common units to generate variance in products. There are various ways to define a module, with the result that there is no distinct definition. For example,

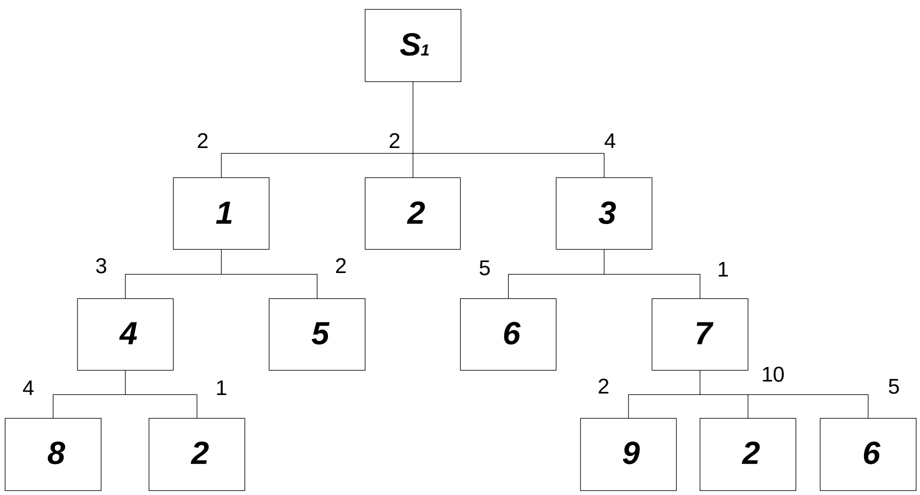


Figure 2.3. An example of product structure

The problem arises as customers attempt to define a module on their own. In order to define the end product (S_1), users or designers may use several ways to define the end product, such as

S_1	=	$S_{1\text{-}1}$	=	(1, 2, 3), or
	=	$S_{1\text{-}2}$	=	(4, 5, 2, 6, 7), or

$$= \quad S_{1-3} \quad = \quad (8, 2, 5, 6, 9).$$

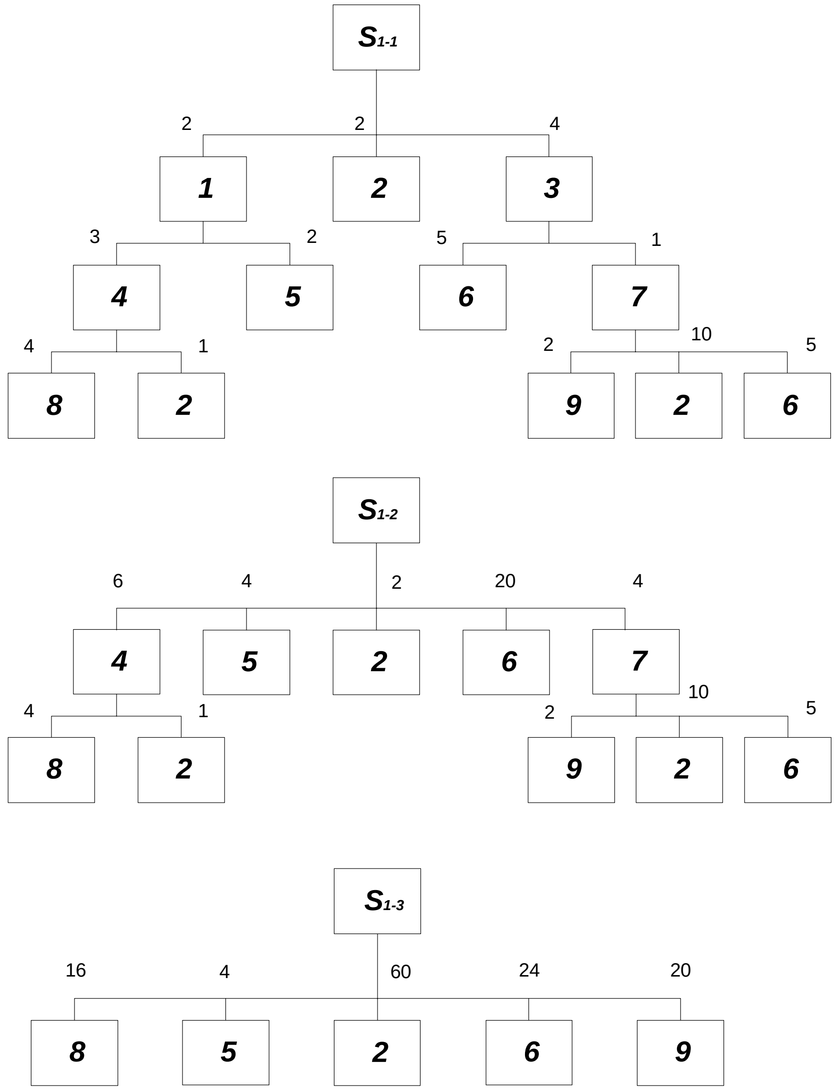


Figure 2.4. An example of different user definitions of product components

It follows that the major difficulty then lies in how the designer responds to this demand and in how the designer retrieves similar products based on different user definitions of modules. Due to these different conceptual design structures, even for the exact same conceptual components, we still have a problem with defining the modules.

Therefore, each designer may get different or even unrelated references when they search the design database.

In summary, there are several different ways to identify a module. Users may use several different ways to identify a complete product. The difficulty still remains in how we are to answer and retrieve similar products based on different user definitions of modules. Many researchers have attempted to characterize product information for product modeling and have defined the meaning of modular products. The difficulty arises when clients attempt to define a module on their own. This results in unsuccessful search outcomes.

2.5. Information and Communication Technology

Presently, global wide enterprises are become common in the manufacturing industry. With shorter developing and manufacturing lead-times, the competitiveness and profitability of an enterprise can be tremendously increased with an international presence. Most industries are users of information and communication technology in some way, because a large part of current business models use internet-based structures to conduct their business. Everyday operations will be automated. A global information network will be connected in the near future. Competitive manufacturing organizations that information connected and knowledge driven have become widely accepted in as leader in the manufacturing environment. Several impact issues of information and communication technology have been discussed in previous studies.

Frutos and Borenstein (2004), discuss the need for an enterprising and effective tool to manage and manipulate the flow of information among participating businesses. The authors proposed the design and implementation of an Internet-based information system framework, which has the capability to adjust to the ever-changing interactions among businesses in a mass-customization environment. This system-framework's most vital and essential contribution is that it communicates with the customer in a way that makes the customer a "co-collaborator" as well. Another benefit of this proposed system is that it enables the company to gather more information about the customer's preferences and needs, which, in turn, also enables the company to generate more customer-oriented products.

In addition, Keil, *et al*. (2000) proposed a research framework to examine the effects of communication technology and information on various management fields. The authors specifically target demand and supply chain management, strategic management, logistics, organization and leadership and management education in their research. Specifically, the authors identify four broad areas of impact of Information and Communication technology: (a) the increase in speed of technological change and turbulence of competitive environments, (b) the decrease of "industry" as the competitive domain of firms, (c) the emergence of a positive feedback industry and d) the increasing importance of standard and technology platform competition. The article also emphasizes the immense speed of the evolution of technological advancements, which also decreases the longevity of any one technological innovation. Moreover, the authors also point out that information and communication technology are used in enterprises outside of the prescribed sector.

With the great technology of the Internet and the World Wide Web, a variety of Web-based applications have been developed and implemented in product design and manufacturing. Many who work in product design and manufacturing have shifted to Web-based environments such as a Web-based manufacturing service system for rapid prototyping (Lan, *et al*. 2004), a Web-based search system of pattern recognition (Hsiao, Sung and Ou, 2004), a Web-based bearing design support system (Cheng, Pan and Harrison, 2001), and remote robot manufacturing (Wang, Chu and Yin, 2001). As one can see from efforts in these Web-based applications, Web technology is accepted as a highly adequate information infrastructure for providing collaboration among organizations.

As a result, Web-based application has become a new highway of communication among customers and enterprises in manufacturing environments. It enables agile manufacturers to promptly communicate with customer demands by eliminating integration barriers. Customers are now able to rapidly customize their product via web-based applications. Past studies have covered several main areas of Web applications. However, to support the utilization of Web applications in product design and manufacturing, manufacturing-specific search engines are still awaited. Regardless of efforts made in developing Web applications, and despite the early promises of Web-based technology, the Web-based approach is still far from being widely accepted (Huang and Mak, 2001a).

2.6. Problem statements

In beginning the design of a product, designers review similar designs of the conceptual product in order to modify it based on reference design patterns. After a review of the relevant literature, the most apparent needs in design retrieval approaches, as well as numerous problems, emerged. They are the following:

2.6.1. Problems of contending with structural product information retrieval

Modular design technologies are effectively improving the speed and cost of new manufacturing products. In addition, modular design of products has been identified as one way of providing firms with a competitive advantage (Ulrich,1995; Kamrani and Salhieh, 2000; Chakravarty and Balakrishnan,2001). Most current researchers study either product data format, structure representation systems (Suh 1998; Kusiak and Huang 1996; Baldwin and Clark, 2000) or shape-based representation systems (Suzuki, et, al., 2002; Funkhouser, *et, al*., 2003). Furthermore, modularity allows firms to develop new technologies incrementally by combining well-understood modules with some portion of new modules. There is research that addresses modularity with respect to structure representation, but the literature still does not offer a system for full function data management or product information retrieval.

2.6.2. Problems of contending with the uncertainty of product modules

Several studies have identified or defined the meaning of modular products. The term *modularity* is frequently used to define the use of common units to generate variance in products (Nam Suh 1998; Huang and Kusiak, 1998; Mikkola and Gassmann 2003; Du, Jiao and Tseng, 2000). Therefore, there are various ways to define a module, with the result that there is no distinct definition. Moreover, the major difficulty then lies in how the designer responds to this demand and how the designer retrieves similar products based on different user definitions of modules.

2.6.3. Problems with the ability to retrieve designs based on modular similarity

Most researchers did not deal with product data retrieval. In addition, those who did contend with product data retrieval, addressed one-level retrieval models, yet did not address multilevel products or structural products (Chang and Tsai, 1997; Tsai and Chang, 2003). Thus, limitations persist in current intelligent retrieval systems.

2.6.4. Problems with gathering product information and product development time

In the past, communication between users and designers has been time-consuming. Product development has been delayed by a lack of instant information exchange, as well as a lack of instant information availability. Vendors, suppliers, manufacturers, and customers may have been located in different places, as well as different time zones. As one can see from efforts in these Web-based applications, Web technology is accepted as a highly adequate information infrastructure for providing collaboration among organizations.

Customers are now able to rapidly customize their product via web-based applications. Past studies have covered several main areas of Web applications.

However, to support the utilization of Web applications in product design and manufacturing, manufacturing-specific search engines are still awaited. Regardless of efforts made in developing Web applications, and despite the early promises of Web-based technology, the Web-based approach is still far from being widely accepted (Huang and Mak, 2001a).

The need for instant communication between vendors, suppliers, manufacturers and customers has become imperative in order to assess and shorten the time for product development. This in turn, will expedite the delivery of products to the market.

Thus, due to the aforementioned problems, it is difficult to set up a system for the design retrieval of structured products. In order to respond to the uncertainty of product modules, to expedite the product development time, as well as to be able to retrieve reference design based on modular similarity, an intelligent retrieval system is essential.

2.7. Research Objectives

The objective of this research is to develop a computer-aided system that assists designers in improving the conceptual design process, by employing modular product design. As stated in the preceding problem statements, there are several problems found in current modular product design technology. Therefore, the aim of this research is to develop a system to enable more effective product design retrieval systems and propose a framework to facilitate a Web-based platform. Thus, the objectives of this research are summarized as follows:

1. Develop a uniform method of representing a product structure that corresponds to different user definitions of modules, due to the variability of customer's views of modules. This uniform method of product structure also must assist the designer in responding to needs of the customer, as well as assist with retrieving similar products based on different user definition of modules.
2. Develop intelligent retrieval algorithms that can deal with structural "*similarity*" for a new or one-of-a-kind product or project. In addition, these intelligent retrieval algorithms should have the ability to search an incomplete query of a structural product or system. Moreover, the intelligent retrieval algorithm can help facilitate retrieval between products with "*weak*" similarities.
3. Develop a platform for modular retrieval system that has the ability to achieve an Internet-based interface retrieval system, which would facilitate e-commerce environment.

CHAPTER 3

USING UNIFIED INDEXING FOR MODULAR PRODUCT RETRIEVAL SYSTEM

3.1. Product module definition

The modularity approach to mass customization provides ways for achieving a high scale of reuse by encouraging the design of products to be based on the same technical systems and manufacturing processes. The problem is that there is not yet a unified framework for supporting modular product design development or for communicating and integrating information which concerns development and order processing.

Moreover, there is no commonly agreed-upon definition of modules as yet. Most definitions claim that a module is a component that is an aggregate of similar functions. Several literatures have identified or defined the meaning of modular products. The term *modularity* is frequently used to signify the use of common units to generate variance in products.

Because there are a variety of ways to characterize a module, a problem arises as customers attempt to define a module on their own. For example, to define the end product of the scissor lift product (P_1) shown in Figure 3.1, the bill of material (including the part description), and the module description are given as following;

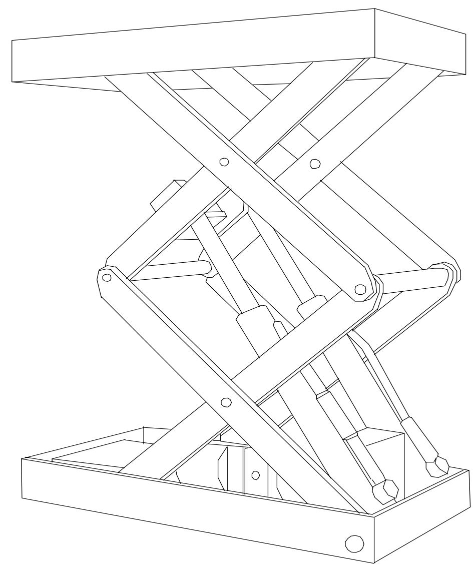


Figure 3.1. An example of lift product (P_1)

The bill of material for Product 1 can be obtained in the following table:

Item	Description	Quantity
1	Base Frame Assembly	1
2	Top Frame Assembly	1
3	Lower Lift Arm Assembly	4
4	Upper Lift Arm Assembly	4
5	Roller Bearing Assembly	4
6	Lift Arm Axle Assembly	2
7	Pivot Pin/Shaft Assembly	4
8	Lift Arm Hinge Pin Assembly	4
9	Hydraulic Cylinder Crosshead Assembly	2
10	Hydraulic Cylinder base pin Assembly	4
11	Hydraulic Cylinder Assembly	2
12	Flow Control Valve	2
13	Hydraulic Reservoir	1
14	Electric Motor	1
15	Pump	1
16	Solenoid Lowering Valve	1
17	Foot switch/Push Button	1

Table 3.1. Bill of material for Product 1 (P_1)

The module description for this example is shown in Table 3.2:

Module	Module Description
Top	Top Deck Assembly
Base	Base Frame Assembly
Lifting	Lifting Unit
Arm	Lifting Arm Assembly
Power	Motor / Pump Assembly

Table 3.2. Product 1 module description

Product P_1 can then be structured as shown in Figure 3.2.

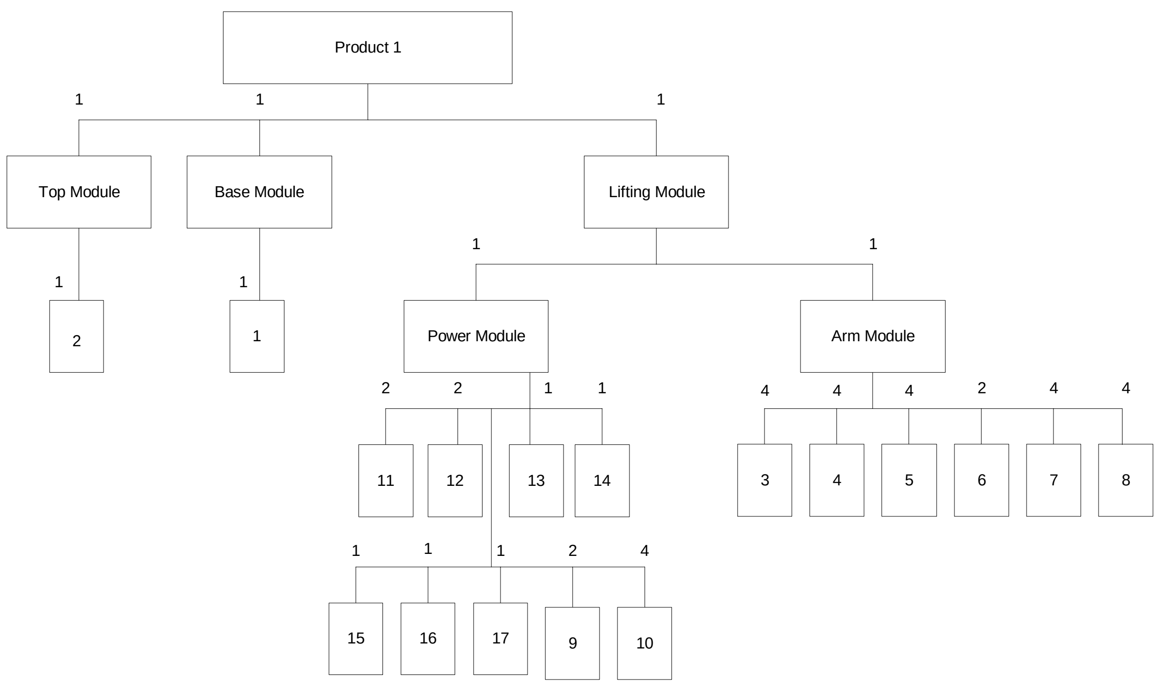


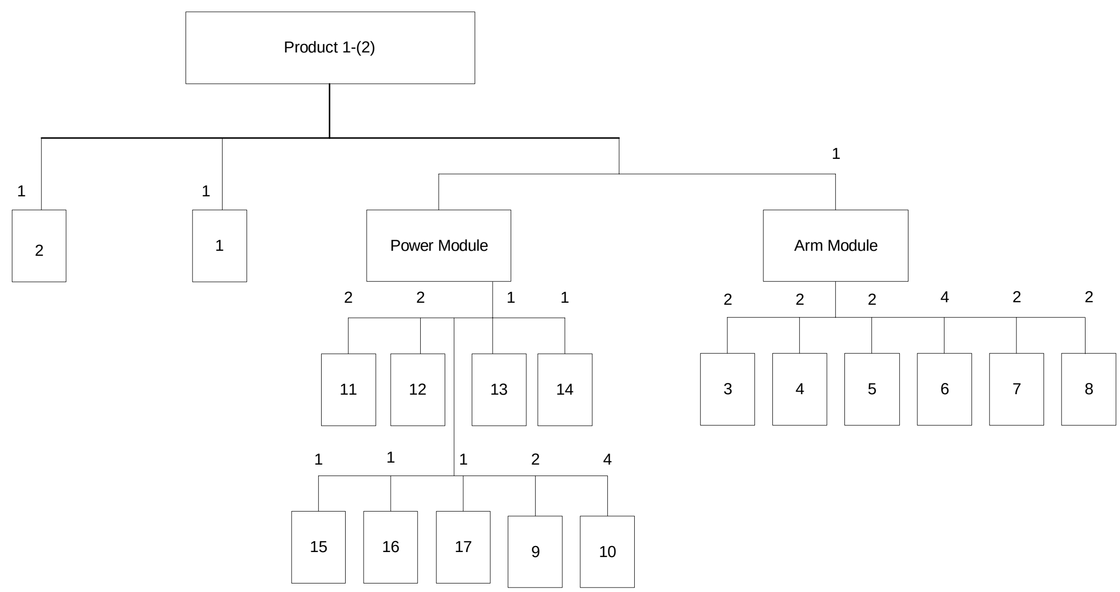
Figure 3.2. An example of a lift product structure

However, users or designers may define the end product in one of several ways, such as

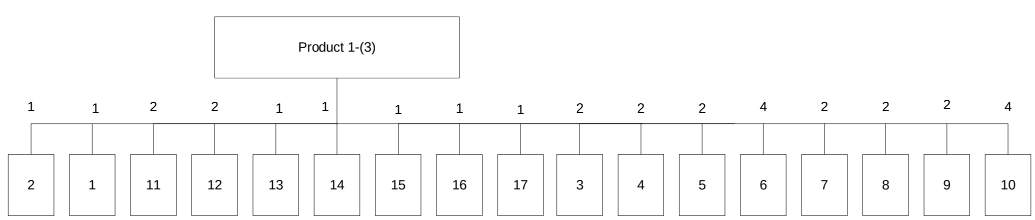
P_1 $= P_{1\text{-}1}$: (Top module, Base module, Lifting module), Figure 3.2, or

$= P_{1\text{-}2}$: (component no. 1, component no. 2, Maneuver module, Arm module), or

$= P_{1\text{-}3}$: (List of all components).



(a)



(b)

Figure 3.3. An example of different users' definitions of a lift product

The major difficulty then lies in how the designer responds to this demand and how the designer retrieves similar products based on different user definitions of modules. As a result, due to these different conceptual design structures, even for exactly the same conceptual components, different designers may get different or even unrelated references when they search the design database.

In summary, there are several different ways to identify a module. Users may identify a complete product in several different ways. The difficulty still remains: how we are to answer and to retrieve similar products based on different user definitions of modules. Many researchers have attempted to characterize product information for product modeling and to define modular products. The difficulty arises as clients attempt to define a module on their own. This results in unsuccessful search outcomes.

Additionally, in spite of which retrieval methods are adopted, the core element determining the failure or success of the product design retrieval system is design knowledge or design indexing. Design indexing is the base and core factor leading to competent product design retrieval. Without the robust support of indexing resources, any kind of design retrieval method or developing mechanism is invalid. In a very large database that supports computer-aided collaborative designs, a proper indexing scheme is crucial whenever the retrieval process has to select a group of reference designs from many possible designs. Therefore, the design indexing methods used for this study's design retrieval systems are introduced.

3.2. Proposed unified indexing scheme

The approach to expedite product development is to retrieve information from the database. Efficient product data management gives the designer the ability to retrieve, redesign, reuse and improve existing products. The need to increase overall performance in the design process makes the retrieval of reference designs attractive to many researchers However, most retrieval techniques are based on one-dimensional information and similarity-based systems are designed for one-level information retrieval.

Currently, many studies have focused on one-dimensional product databases. The outcome of these works show that the one-dimensional product database results in an unsuccessful search outcome for structural products, because it is unable to retrieve a similar result at different levels. Moreover, the problem still is that there is not yet a unified method for supporting product structure development and for integrating information. This concerns the initial design as well as the reuse of modules and of product structures when creating new products.

To answer the aforementioned difficulty, a unified indexing method introduced with this study. This proposed indexing method requires information about (1) product structure, and (2) component information.

As stated in the problem statement, most researchers do not deal with product data retrieval in terms of modular products. In fact, those who did contend with product data retrieval addressed one-level retrieval models (Chang and Tsai, 1997; Tsai and Chang, 2003), but excluded multi-level products or structural products. In addition, there are difficulties in representing product structure, because users define product modules differently. Therefore, we proposed a unified indexing scheme for a modular product structure database in a numerical format for use with a product retrieval system. An approach to obtain a unified indexing scheme is introduced by the use of the next assembly quantity matrix (Vazsonyi, 1958, Chang, Brown, Johnson, 1983). The adopted next assembly quantity matrix for a unified indexing scheme is represented as follows:

The information from Figure 3.2 can then be represented in numerical form as the next assembly quantity matrix. The next assembly quantity matrix *N* shows how many of each assembly or module is required in any other module. The next assembly matrix *N* can be written as:

$$N = \begin{bmatrix} 0 & 0 & . & . & . & 0 \\ n_{21} & 0 & & & & 0 \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ n_{x1} & n_{x2} & . & . & . & 0 \end{bmatrix} \tag{3.1}$$

where n_{xy} is the quantity of the next assembly module which corresponds to the bill of material.

With reference to Figure 3.2, the demonstration of components and structure information is as follows. Starting from a finished product, designers specify all the product modules in the design. Product modularity can be represented based on the component types of combinations between the modules. Let *P* be a finished product:

$$P = \{m_{ij} \mid m_{ij} \in \mathrm{M}\} \tag{3.2}$$

where

m_{ij} = module j at level i and i , j = 1, 2, 3, …, n.

M = a set of product module

Designers construct a design by combining components from the bottom up. In the component library, each component has its related interface with others, specific manufacturing meaning, and related processes that can be easily coordinated with downstream activities.

However, the next assembly quantity matrix, N, only shows how many of each components are required directly for the parent module. There is still a problem to determine how many of each module are required in total for every other module.

Let $\boldsymbol{N^2}$ be the second-level next assembly matrix if we want to see how many of each component is needed for the second-level of the next assembly matrix. Likewise, this applies for $\boldsymbol{m^{th}}$-level of the next assembly matrix.

Therefore, we can obtain the following matrix to represent the product component and structure matrix, S_i, for product i as

$$S_i = N_i + N_i^2 + N_i^3 + \ldots + N_i^m \tag{3.3}$$

where m is the last level of the product structure

When m is greater than the number of product structure layer, we obtain

$$N_i^m = \begin{bmatrix} 0 & 0 & . & . & . & 0 \\ 0 & 0 & & & & 0 \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ 0 & 0 & . & . & . & 0 \end{bmatrix}$$

because N is triangular matrix as shown in (3.1).

Thus, we can rewrite Equation 3.3 as follows;

$$S_i = \left(I + N_i + N_i^2 + N_i^3 + \ldots + N_i^\infty\right) - I$$

$$= \frac{I - N_i^\infty}{I - N_i} - I$$

$$= \frac{I}{I - N_i} - I$$

$$= \left(I - N_i\right)^{-1} - I \qquad (3.4)$$

we can rewrite Equation 3.4 as

$$S_i = T - I \qquad (3.5)$$

and,

$$T = (I - N)^{-1} \qquad (3.6)$$

where

T is the total requirement factor matrix

I is the identity matrix

N is the next assembly quantity matrix

S_i matrix is suggested as a unified indexing scheme for a design database. Once the unified index scheme is determined, a retrieval system is required to complete the mechanics of retrieval. It is useful in such situations as dealing with product representation, information storage, organization, and access to product information. It is essential for a retrieval method to have the ability to scan the database, to integrate modules in meaningful ways, and to evaluate similar products. A design information retrieval system should provide a user with easy access to the information.

3.3. Utilizing unified indexing with Fuzzy-ART neural network

In order to retrieve a modular product, a Fuzzy-ART neural network is recommended to achieve the task. It provides designers with the flexibility to select relevant design cases. Artificial neural networks (ANNs) and Fuzzy theory (Zadeh, 1965) are two important soft computing technologies. As a matter of fact, these two technologies complement each other in the design of an intelligent system (Chou and Ho, 1999). Introduced in 1991 by Carpenter, Grossberg and Rosen, Fuzzy-ART is an unsupervised category learning and pattern recognition network. It incorporates computations from fuzzy set theory into the Adaptive Resonance Theory (ART)-based neural network.

A typical ART network consists of two layers: and input layer and an output layer. There are no hidden layers. The input layer has *n* input nodes while the output layer is decided dynamically. However, ART architecture extends the competitive learning network to a framework which possesses important properties for strictly binary inputs.

In contrast, Fuzzy-ART is capable of rapid stable clustering of continuous or binary input patterns; other algorithms for clustering purposes require lengthy processing and storage and manipulation of large matrices. Compare to other design retrieval mechanism, Fuzzy-ART has a superior classification performance particularly in industry-size problem application (Suresh and Kaparthi, 1994). Moreover, Fuzzy-ART is capable of retrieving similar designs instead of identical designs as well as incomplete query capability. With some lost information, Fuzzy-ART is able to retrieve similar or exact designs (Chang and Tsai, 2001).

Since a Fuzzy-ART neural network operates in an associative way, it can tolerate an incomplete query and still find most similar reference designs. By adjusting the similarity parameter of the network, designers may adjust the similarity of retrieved reference designs. The implementation result shows that the proposed system is flexible in several ways.

There is a special function of this retrieval system. If there is a new component presented in a query and the total requirement factor matrix does not contain it, with the capability of a Fuzzy-ART neural network, we can neglect that component and handle the case as an incomplete information query. Moreover, there are different numbers of components in one product design. A Fuzzy-ART neural network is suggested to be a suitable method for this research.

Let $\vec{S}$ be *N-dimensional* input vector and

$$\vec{S} = (S_1, \ldots, S_i, \ldots, S_N) \tag{3.7}$$

where S_i = a component and structure matrix of product *i*

The Fuzzy-ART neural network attempts to classify each input into one of its existing categories, based on the input's similarity to the stored prototype of each category node. For input $\vec{S}$ and each category node *j*, the choice function $T_j(\vec{S})$ is

$$T_j(\vec{S}) = \frac{\left|\vec{S} \wedge \vec{w}_j\right|}{\alpha + \left|\vec{w}_j\right|} \tag{3.8}$$

The pattern that defines each category (*j*) is a weight vector

$$\vec{w}_j \equiv (\vec{w}_{j1},\dots,\vec{w}_{jm}) \tag{3.9}$$

Initially,

$$\vec{w}_{j1} = \vec{w}_{j2} = \dots = \vec{w}_{jm} = 1 \tag{3.10}$$

where the choice parameter $\alpha > 0$. The fuzzy intersection (Zadeh 1965) operator $\wedge$ is defined by

$$(\mathbf{x} \wedge \mathbf{y})_i \equiv \min(x_i, y_i) \tag{3.11}$$

and the norm $|\cdot|$ is defined by

$$|x| \equiv \sum_{i=1}^{M} x_i \tag{3.12}$$

for any *M*-dimension of vector *x*. An input is classified into the j^{th} category, and the j^{th} in the output layer is activated if it received the largest input. The network then makes a category choice by select node *j* where

$$T_J = \max\{T_j : j = 1, 2, \dots, N\} \tag{3.13}$$

If there is more than one index *j* given a maximal T_j, the node with the smallest index is chosen. Thus, nodes are committed in order *j* = 1, 2, 3, ….

By definition resonance is said to occur if the match function of the chosen node meets the following vigilance criterion.

$$\frac{|\vec{S} \wedge \vec{w}_J|}{|\vec{S}|} \geq \rho \tag{3.14}$$

Choice parameter α and vigilance parameter ρ determine the network where $\alpha > 0$ and $\rho \in [0,1]$ respectively. Therefore, the Fuzzy-ART neural network proposed in this research takes a unified structure and component matrix as input in order to achieve the modular product retrieval task. Specially, a full overview of the Fuzzy-ART algorithm is shown in Appendix A.

Fuzzy-ART neural network computes the choice function, T_j. Also, for each output node, j = 1 to N. Further, the output node j, with the largest T_j value, is selected. However, it is necessary to check whether this best matching meets the specified level of similarity in ρ . If this similarity level is greater than the specified ρ value, the part is classified under that class. The best-matching weight is also updated by modifying the associated weight vectors. However, if it does not pass the similarity level, a new weight is updated to reflect the new input. Thus, the process is repeated until all inputs are processed.

From vigilance criterion (Equation 3.14), considering component and product structures, if a component and product structure for product 1, s_1 , and a component and product structure for product 2, s_2 , are classified under the same class at a specified similarity level , ρ , value of k based on previous experiences, then it is considered that product 1, s_1 , and product 2, s_2 ,the same product.

The measurement of similarity can be implemented for multiple views of a single modular product in the design database when each is defined in multiple modular product views. Therefore, at a specified similarity level, ρ , we can conclude Corollary 1(a) and Corollary 1(b) as follows;

Corollary 1

Suppose the component and structure matrix, S_i, is a feasible structural view of a modular product, P, and let $\mathrm{X} = \{ S_i \mid i \in \{1, 2, ..., m\}\}$ in which X is a set of component and structure matrices, such that

$$P \subseteq \mathrm{X} ,$$

where m is the number of structural views.

Let similarity measurement, ρ, from Fuzzy-ART neural network be

$$\rho = \frac{\sum_i \min(S_i : w)}{\sum_i S_i},$$

where $w \in (0,1)$ is a weight vector .

(a)

If k is a specified similarity value based on previous experiences, where S_i and S_j are grouped in the same cluster under $\rho > k$, and

$$S_i \subseteq P \quad , \forall i \in \{1, n\};$$

$$S_j \subseteq P \quad , \forall j \in \{1, n\},$$

then, we conclude that members of S_M, where

$S_M = \{ S_i , S_j \mid S_i \subseteq P ; S_j \subseteq P, \forall j \in \{1, n\}, \forall i \in \{1, n\}, \rho > k \},$

can be the same product.

(b)

Since member of product structure view set, S_M**,** are considered as similar product where

$$S_M = \{ S_i , S_j \mid S_i \subseteq P ; S_j \subseteq P, \forall j \in \{1, n\}, \forall i \in \{1, n\}, \rho > k \},$$

and the component and structure matrices, S_i and S_j, are feasible structural views of a modular product, P. Consequently, if

$$S_i = T_i - I ,$$

where

$$T_i = (I - N_i)^{-1}, \text{and}$$

I is the identity matrix, and

N_i is the next assembly quantity matrix, and

$i \in \{1,2,\ldots,m\}$,

then S_i can be regarded as the unified index for the retrieval of similar modular products, which can be utilized to accommodate different module views.

Moreover, if a component and product structure matrix for product 1, S_1, and a component and product structure for product 2, S_2, are classified under the same class at any similarity level ρ, then it is considered that the products are similar to each other in that product group. This means that the measurement of similarity from Corollary 1(a) not only works for multiple views of a single modular product, but it is also means it is able to distinguish the amount of difference among modular products in the design database when each of them is defined in multiple modular product views. We can conclude Corollary 2 as follows:

Corollary 2:

Let a component and structure matrix, S_{ij}, be a feasible structural view of a modular product P_j, and S_{ij} is regarded as the unified index for the retrieval of modular product similarity.

Let $\mathrm{X} = \{ S_{ij} \mid i \in \{1, 2, ..., n\}, j \in \{1, 2,..., m\}\}$ in which X is a set of component and structure matrices, where n is the number of structural views and m is a number of modular products.

If S_{ij} is utilized as input for a Fuzzy-ART neural network similarity measurement,

$$\rho = \frac{\sum_i \min(S_{ij} : w_j)}{\sum_i S_{ij}},$$

where $w \in (0,1)$ is a weight vector, and

$$S_{ij} \subseteq P_j, \quad \forall i \in \{1, n\};$$

$$P_j \subseteq X, \quad \forall j \in \{1, m\},$$

then, P_j*'s* are clustered according to corresponding modular product sets, X_r, such that $\mathrm{X}_r = \{ P_j \mid j \in \{1, 2,..., m\}\}$ can be a set of modular products under a value of ρ, where $r \in \{1, 2,..., m\}$.

3.4. Building a structural product membership data for Fuzzy-ART neural network with component quantity

Before entering Fuzzy-ART neural network, a component and structure matrix of product *j*, S_j, is indexed by a set of component based module, which can be represented into vector format $\vec{S}_j$. As a result, a component and structure matrix input vector for product *j* from Equation 3.4 can be described as the following:

$$S_j = \begin{bmatrix} s_{11} & s_{12} & . & . & . & s_{1y} \\ s_{21} & . & & & & . \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ s_{x1} & s_{x2} & . & . & . & s_{xy} \end{bmatrix} \tag{3.15}$$

In order to retrieve a modular product, a Fuzzy-ART neural network is recommended to achieve the task. There are different numbers of components in one product design. Since Fuzzy-ART is capable of rapid stable clustering of continuous or binary input patterns we suggest using a membership measurement as continuous input patterns.

Thus, we can represent a component and structure matrix input pattern as

$$\vec{S}_j = \begin{bmatrix} \mu_{(j,1,1)} & \mu_{(j,1,2)} & . & . & . & \mu_{(j,1,y)} \\ \mu_{(j,2,1)} & . & & & & . \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ \mu_{(j,x,1)} & \mu_{(j,x,2)} & . & . & . & \mu_{(j,x,y)} \end{bmatrix} \tag{3.16}$$

where $\mu_{(j,x,y)}$ is a membership measurement associated with the quantity of component as it appears in product *j*.

Starting from a finished product, designers specify all the product modules in the design by applying the component and structure matrix indexing scheme until there is no further decomposition of a design.

In this study, each product is indexed according to our proposed unified indexing scheme. We can define membership measurement $\mu_{(j,x,y)}$ for each module as the following:

$$\mu_{(j,x,y)} = \frac{q\,(j,x,y) - \min_{(x,y)}}{\max_{(x,y)} - \min_{(x,y)}} \qquad , \ \forall j \in \{1, n\} \tag{3.17}$$

where $\max_{(x,y)} = \max_{j \in N} \{q\,(j,x,y)\}$

$\min_{(x,y)} = \min_{j \in N} \{q\,(j,x,y)\}$

If $\max_{j \in N} \{q\,(j,x,y)\} = \min_{j \in N} \{q\,(j,x,y)\}$, then $\mu_{(j,x,y)} = 0$,

where $q\,(j,x,y)$ is the quantity of a component appears matrix S_j at position (*x*,*y*).

n is a number of products.

Therefore, we can conclude a component and structure input pattern with membership measurement as follows:

$$\vec{S}_j \quad \equiv \quad [S_j \otimes \mu_{(j,x,y)}] \tag{3.18}$$

3.5. A unified indexing scheme example

Consider the product in Figure 3.4 as an example:

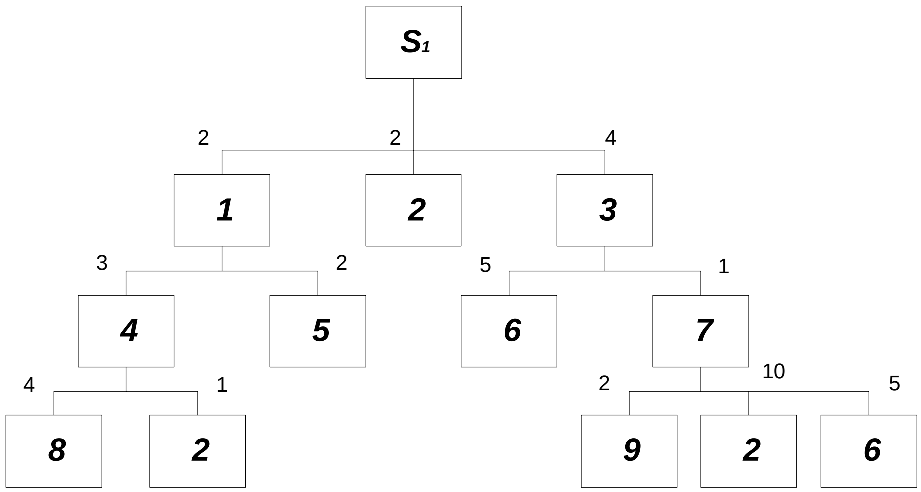


Figure 3.4. An example of a modular product

When customers attempt to define a module on their own, they may define the end product in several ways. According to the aforementioned figure,

S_1 = $S_{1\text{-}1}$ = (1, 2, 3), or

= $S_{1\text{-}2}$ = (4, 5, 2, 6, 7), or

= $S_{1\text{-}3}$ = (8, 5, 2, 6, 9).

Consider the following example: $S_{1\text{-}1}$, $S_{1\text{-}2}$, and $S_{1\text{-}3}$ are classified according to different module views.

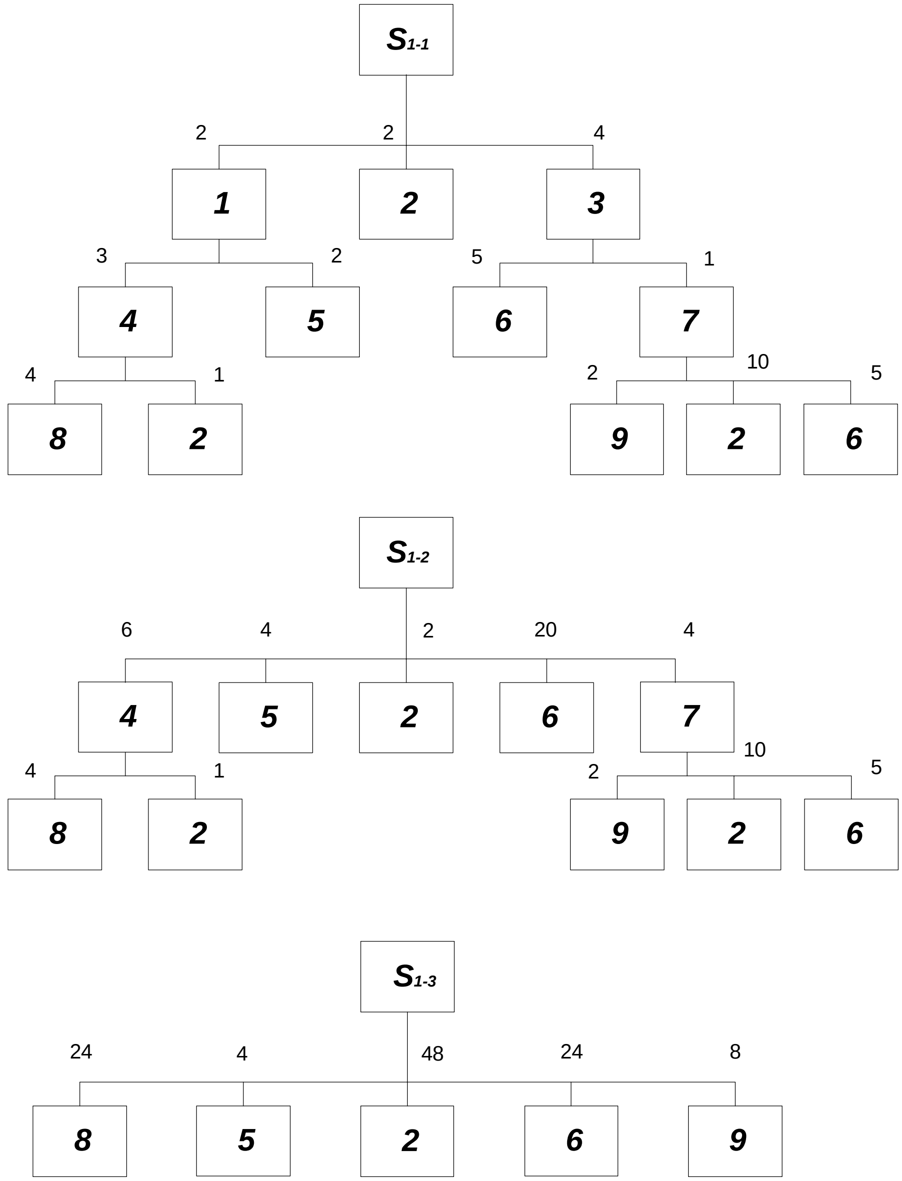


Figure 3.5. An example of different users' definitions of product component

The values in the *S* matrix are the component and structure information of all items corresponding to the requirement of final products and service components for each period. Since there is no clear definition for a module of a product, as mentioned earlier, we need to utilize a component and structure, *S,* matrix model as a common base module. Regardless of the definition of the module, the *S* matrices will remain similar to each other. Once every product is completely indexed, the retrieval process can then be initiated. The designer then examines the set of ranked products for useful information.

In databases, indexing and retrieval are related to each other. The selection of an indexing technique for a retrieval system is one of the most important factors in determining the performance of the system. Indexing data for a database can significantly influence the way in which information can be retrieved.

Applying our proposed indexing scheme to product structures in Figure 3.5, we obtain component and structure matrices as input pattern. We are able to determine *N* and *S* matrix for each one of product. For $S_{1\text{-}1}$, $S_{1\text{-}2}$ *and* $S_{1\text{-}3}$, *N* and *T* matrix are as following:

$$\begin{array}{cccccccccc} S_1 & 1 & 3 & 4 & 7 & 2 & 5 & 6 & 8 & 9 \end{array}$$

$$N_{1-1} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 1 & 10 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 5 & 0 & 5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{array}{c} S_1 \\ 1 \\ 3 \\ 4 \\ 7 \\ 2 \\ 5 \\ 6 \\ 8 \\ 9 \end{array}$$

$$S_{1-1} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 6 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 48 & 3 & 10 & 1 & 10 & 0 & 0 & 0 & 0 & 0 \\ 4 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 40 & 0 & 10 & 0 & 5 & 0 & 0 & 0 & 0 & 0 \\ 24 & 12 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 0 & 2 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{array}{c} S_1 \\ 1 \\ 3 \\ 4 \\ 7 \\ 2 \\ 5 \\ 6 \\ 8 \\ 9 \end{array}$$

$$S_2 \quad 1 \quad 3 \quad 4 \quad 7 \quad 2 \quad 5 \quad 6 \quad 8 \quad 9$$

$$N_{1-2} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 1 & 10 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 20 & 0 & 0 & 0 & 5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{matrix} S_1 \\ 1 \\ 3 \\ 4 \\ 7 \\ 2 \\ 5 \\ 6 \\ 8 \\ 9 \end{matrix}$$

$$S_{1-2} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 48 & 0 & 0 & 1 & 10 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 40 & 0 & 0 & 0 & 5 & 0 & 0 & 0 & 0 & 0 \\ 24 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{matrix} S_1 \\ 1 \\ 3 \\ 4 \\ 7 \\ 2 \\ 5 \\ 6 \\ 8 \\ 9 \end{matrix}$$

$$\begin{array}{cccccccccc} S_3 & 1 & 3 & 4 & 7 & 2 & 5 & 6 & 8 & 9 \end{array}$$

$$N_{1-3} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 48 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 40 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 24 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{array}{c} S_1 \\ 1 \\ 3 \\ 4 \\ 7 \\ 2 \\ 5 \\ 6 \\ 8 \\ 9 \end{array}$$

$$S_{1-3} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 48 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 40 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 24 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{array}{c} S_1 \\ 1 \\ 3 \\ 4 \\ 7 \\ 2 \\ 5 \\ 6 \\ 8 \\ 9 \end{array}$$

From above illustration, component and structure matrices, S_{1-1} , S_{1-2} and S_{1-3} are indexed using a unified indexing scheme. Since Fuzzy-ART is capable of rapid stable clustering of continuous we suggest using a membership measurement as continuous input patterns. Thus, we can represent component and structure matrices input pattern as

$$S_j = \begin{bmatrix} \mu_{(j,1,1)} & \mu_{(j,1,2)} & \cdot & \cdot & \cdot & \mu_{(j,1,y)} \\ \mu_{(j,2,1)} & \cdot & & & & \cdot \\ \cdot & & \cdot & & & \cdot \\ \cdot & & & \cdot & & \cdot \\ \cdot & & & & \cdot & \cdot \\ \mu_{(j,x,1)} & \mu_{(j,x,2)} & \cdot & \cdot & \cdot & \mu_{(j,x,y)} \end{bmatrix}$$

where

$$\mu_{(j,x,y)} = \frac{q\,(j,x,y) - \min_{(x,y)}}{\max_{(x,y)} - \min_{(x,y)}} \qquad , \forall j \in \{1, n\}, \text{ and}$$

$$\max_{(x,y)} = \max_{j \in N}\{q\,(j,x,y)\}, \text{ and}$$

$$\min_{(x,y)} = \min_{j \in N}\{q\,(j,x,y)\}.$$

After applying membership measurement from Equation 3.18 and implementing Corollary 1(a), we consider the similarity parameter , $\rho > 0.9$, from Fuzzy-ART neural network algorithm for three *S* matrices of these three modular structures. The result is shown in Table 3.3.

Similarity parameter: 0.9	
Cluster 1	$\boldsymbol{S_{1\text{-}1}}$, $\boldsymbol{S_{1\text{-}2}}$, $\boldsymbol{S_{1\text{-}3}}$

Table 3.3. A similarity result of different module definitions of the same product

It means that the similarity of these three modular structures by different views of users is larger than 0.9. We can conclude that $S_{1\text{-}1}$, $S_{1\text{-}2}$, $S_{1\text{-}3}$ are from the very same modular product.

Traditionally, if we consider product component levels of only two products, we can see they are similar. Consider the following example;

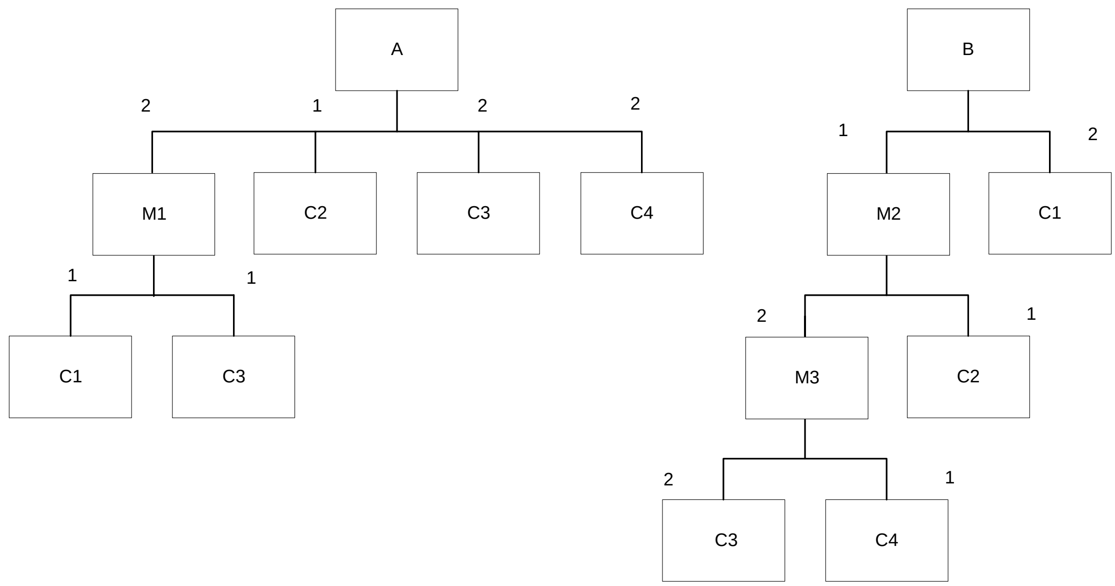


Figure 3.6. Examples of alternative product structure

	C1	C2	C3	C4
A	2	1	4	2
B	2	1	4	2

Table 3.4. A and B product components

$$S_A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}; \qquad S_B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 4 & 2 \\ 2 & 0 & 0 & 0 & 0 & 0 & 2 & 1 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \end{bmatrix}$$

As we can see from the *S* matrix, they are different from each other. S_A and S_B are separated and clustered in different groups when similarity parameter, ρ, > 0.3. As a result, the *S* matrix is an appropriate method to distinguish the dissimilarity of these previously mentioned obstacles that traditional retrieval method would not recognized the differences.

This measurement of similarity works not only for multiple views of a single modular product, but also can distinguish the amount of difference among modular products in the design database when each of them is defined in multiple modular product views. For example, when modular products are defined in multiple modular product views, the result (see Appendix B) is as follows:

ρ = 0.9	
cluster # 1:	$S_{1\text{-}1}$ $S_{1\text{-}2}$ $S_{1\text{-}3}$
cluster # 2:	$S_{2\text{-}1}$ $S_{2\text{-}2}$ $S_{2\text{-}3}$
cluster # 3:	$S_{3\text{-}1}$ $S_{3\text{-}2}$ $S_{3\text{-}3}$

Table 3.5. A result of an example of different product with different module definition

Table 3.5 shows three clusters, each containing multiple modular product views of a single product. In conclusion, the *S* matrix can accomplish unified indexing because it has the ability to handle different modular views and different structural products. The representation and organization of the *S* matrix should provide a user with effective access to the information. Furthermore, a user can retrieve not only similar structural products based on a similarity level for the purpose of conceptual design, but a user can reference similar modular products within his or her organization for business purposes.

In a very large database that supports computer-aided collaborative designs, a proper indexing scheme is crucial whenever the retrieval process has to select a group of reference designs from many possible designs.

Using an *S* matrix as a unified indexing scheme is an excellent way to achieve an application of modular design retrieval because:

1. It establishes a uniform indexing method with a unique representation of a specific view for a modular product.
2. It embeds all modular structure information as well as all components in one representation.

3.6. Embedding modular structural indexing into product database

Product designers develop large collections of products that they construct or make use of throughout their design histories. Database is the study of the data structures used to store collections of data in order to allow for efficient search and retrieval. Product design development, like most other business processes, requires database support to achieve a good conceptual design. However, there is a problem in that existing databases have been used for many years and no one seems willing to create a new database. We need a mechanism to transform an existing database into a unified indexing database. As the number of products grows in such an archive, the understanding and utilizing of them becomes tremendously complicated. In this study, we have implemented a retrieval methodology and have proposed a unified indexing scheme to search the database, as well as to change the way in which conceptual product designers and manufacturers view data management problems.

The database stores all information regarded to product information and component information. A relational database is performed as a set of tables. An example of a relational instance in database module is a set of records, in which each record has the same number of fields as the relation schema. A relation instance can be thought of as a table in which each record is a row and all rows have the same number of fields. A product/component database is the most common type used in a database management system. These systems index only models based on simple properties that have little or nothing to do with the structure of the part, such as part name or the designer’s name.

Many design database systems currently ignore content- and structure-based analysis of the products they contain. Databases of structural products that do make use of high-level, content-based analysis of the models typically rely on manual classification techniques, such as group technology coding. The task of manual indexing is error-prone, depends on the personal judgment of the observer, and is expensive.

Furthermore, in the past, many studies have focused on the two-dimensional product databases, a set of tables. The outcome of these works show that the two-dimensional product database results in an unsuccessful search outcome when it comes to structural product retrieval, because there is no way to retrieve a similar result at different levels.

By adding one more dimension, or product component structure level, to the conventional data table, the retrieval of such modular systems becomes even more confusing. This study presents a technique for organizing data into a present relational database management system. We extend a technique of converting a database to assist all the way through our proposed indexing scheme and retrieval system. The goal is to enable support for our proposed system to be able to retrieve reference designs from large databases of modular products.

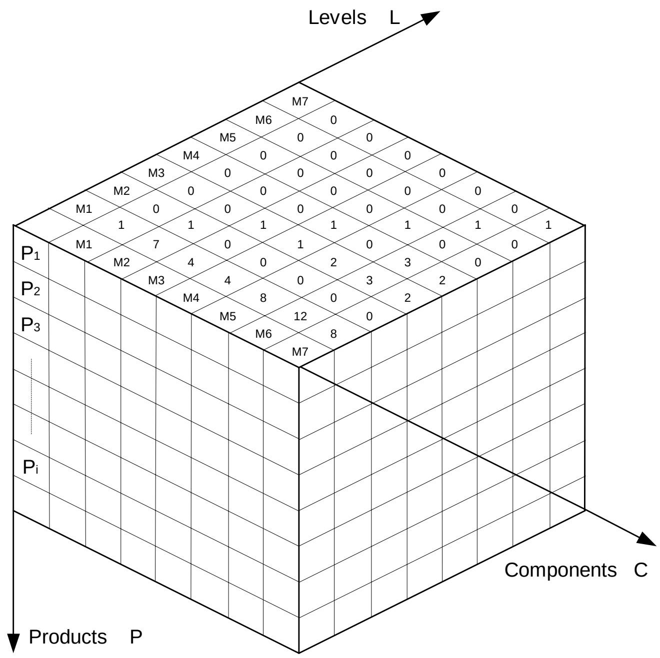


Figure 3.7. Three-dimensional product component structures

Characteristically, a database system function is to store information and to let users retrieve and update that information on demand. The main construct for representing data in the relational model is a relation. A relation contains a *relation instances* and *relation schema*. A relation instance is a table, and the relation schema describes the column heads for the table. The schema indicates the relation's name, the name of each field (or column or attribute), and the domain of each field. A domain is referred to in a relation schema by the domain name and has a set of associated value.

An example of a relation instance is a set of records, in which each record has the same number of fields as the relation schema. A relation instance can be thought of as a table in which each record is a row and all rows have the same number of fields. Let

$R(f_1 : D1, \ldots, f_n : Dn)$ be a relation schema, and for each function $f_i, 1 \le i \le n$, let d_i be the set of values associated with the domain named D_i. An instance of R that satisfies the domain constrains in the schema is a set of records with *n* fields:

$$R \quad = \quad \left\{ \left\langle f_1 : d_1, \ldots, f_n : d_n \right\rangle \mid d_1 \in D_1, \ldots, d_n \in D_n \right\} \tag{3.19}$$

Moreover, a common product design and its component can be considered as a record in a database. Let p_i be a product *i*, and a record in a relation product/components as following:

$$p_i \quad = \quad \left\{ \left\langle c_1 : q_1, \ldots, c_j : q_j, \ldots, c_n : q_n \right\rangle \mid q_1 \in Q_1, \ldots, q_j \in Q_j, \ldots, q_n \in Q_n \right\} \tag{3.20}$$

where

c_j = component /or module *j*

q_j = a quantity of component /or module *j*

We can write in term of relation as

$$p_i \quad = \quad \left\{ \left\langle \{c_j\} : \{q_j\} \right\rangle \mid q_j \in Q_j, j \in \mathrm{N} \right\} \tag{3.21}$$

where

$\{ q_j \}$ is a set quantity of each module for each product.

Let *D* be a product design database, then

$$D \quad = \quad \bigcup_{p_i \in D} p_i \quad , \quad i \in \mathrm{N} \tag{3.22}$$

The problem remains that there is not yet a method for supporting product structure development and for integrating information. This concerns initial design, as well as the reuse of modules and of product structures when creating new products. By adding one more dimension product component structure level to the conventional database, we are able to obtain a structural-based product relation model. The additional dimension is considered by adding the next assembly relation.

Let N_i be next assembly relationship,

$$N_i = \text{(components, next assembly component), or}$$

$$= (c_j : \textit{next components})$$

$$= \left\{ \left\langle c_j : \{\{c_j\} : \{q_j\}\} \right\rangle \mid q_j \in Q_j, j \in \mathrm{N} \right\} \quad (3.23)$$

Let S_i be a component and product structure relationship, which is regarded as the unified index such that

$$S_i = (I - N_i)^{-1} - I \quad (3.24)$$

Let M will be a modular product database with structural information. As we go through the database of an organization, we can obtain the component and product structure relations (see Equation 3.5) for the database,

$$M = \bigcup_{p_i \in D} p_i \cap N_i \quad (3.25)$$

Thus, we can represent a structural product database for an organization in terms of an existing database relation model and next assembly product information as follows:

$$M = D \bigcap_{i \in \mathrm{N}} N_i \quad (3.26)$$

By adding the next assembly relationship to the database as another dimension of a database, we can summarize the above elaboration to the following corollary:

Corollary 3:

Suppose a product, p_i , is a tuple in a product/component relationship as follows:

$$p_i \quad = \quad \left\{ \left\langle \{c_j\}:\{q_j\} \right\rangle \mid q_j \in Q_j ,\, j \in \mathrm{N} \right\},$$

where c_j = component /or module j and,

q_j = a quantity of component /or module j.

A product database can be created as $D \quad = \quad \bigcup_{p_i \in D} p_i \quad , \quad i \in \mathrm{N}$.

If the next component assembly relationship, N_i, can be denoted as

$$N_i = \quad \left\{ \left\langle c_j : \{\{c_j\}:\{q_j\}\} \right\rangle \mid q_j \in Q_j ,\, j \in \mathrm{N} \right\}, \text{ and}$$

S_i is a component and product structure relationship, which is regarded as the unified index such that $S_i \quad = \quad \left(I - N_i\right)^{-1} - I$,

then a product database is integrated with a component and structural relationship information as

$$\bigcup_{p_i \in D} p_i \quad \cap \quad N_i \, .$$

Therefore, a modular product database, M, can be represented as follows:

$$M \quad = \quad D \bigcap_{i \in \mathrm{N}} N_i$$

In databases, indexing and retrieval are related to each other. The selection of an indexing technique for a retrieval system is one of the most important factors in determining the performance of the system. Many component-based indexing schemes have been developed for design retrieval systems. However, as the number of products grows in such an archive, the understanding and utilizing of them becomes tremendously complicated.

Traditionally, a product database only contained product components information. It lacks components and structural information integration. It is difficult to retrieve a reference product only using component information as query input for structural similarity products. It means that one-dimensional product database results in an unsuccessful search outcome when it comes to structural product retrieval, because there is no way to retrieve a similar result at structural levels. Therefore, a mechanism to transform an existing database into a modular structural product database is needed.

Using Corollary 3, we extend a technique of converting a database to assist all the way through our proposed indexing scheme and retrieval system. From Corollary 3, a modular structural product database M is an important element for the proposed retrieval system because it gives a designer not only an ability to retrieve products based on structural similarity, but also an ability to retrieve from any existing product databases that lack a component and structure information. The objective is to enable support for our proposed system to be able to retrieve reference designs from existing databases based on modular structural similarity.

3.7. Conclusion of proposed methodology

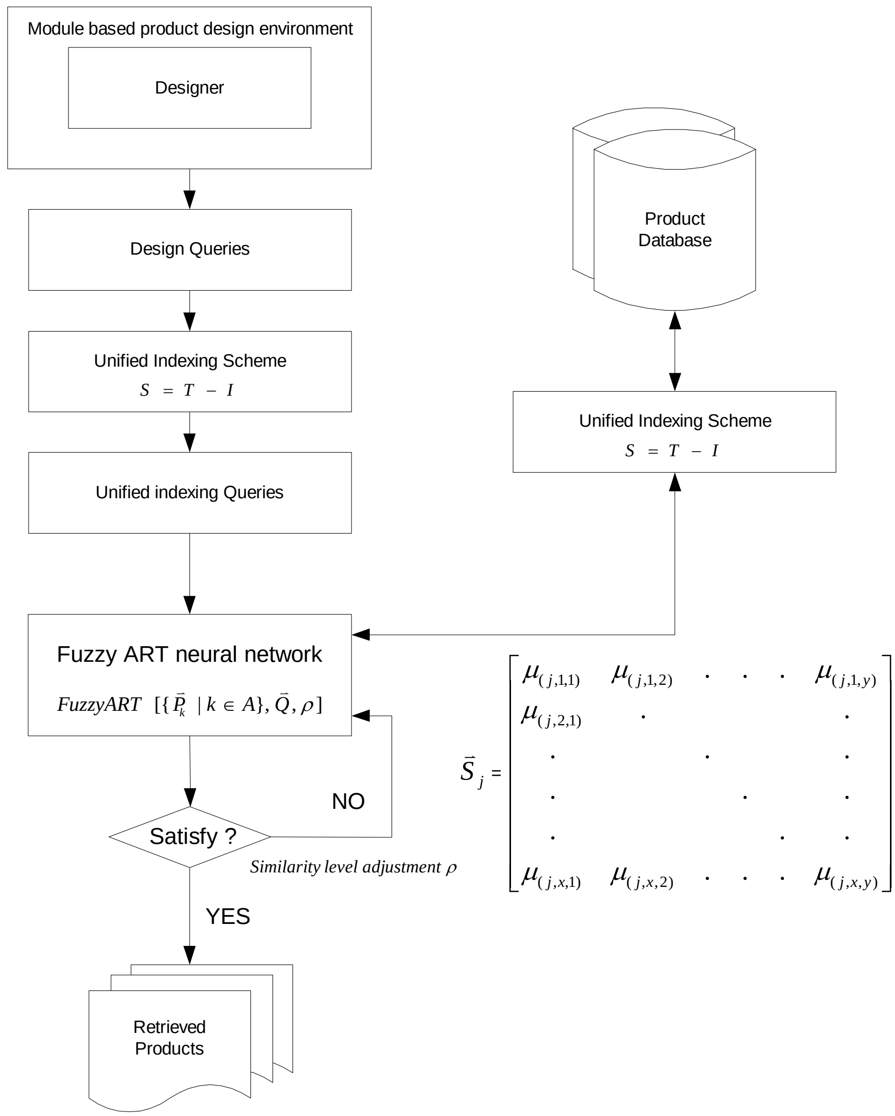


Figure 3.8. Flowchart of the proposed system

At a design stage, a user normally searches for similar products instead of starting from zero. A modular product design can be defined through an indexing method as a mapping process from component and product structure to a solution space in order to fulfill a modular product retrieval tasks. In a very large database that supports computer-aided collaborative designs, a proper indexing scheme is crucial whenever the retrieval process has to select a group of reference designs from many possible designs. Even though some studies have implemented processes of indexing and retrieving for new product developments, limitations still exist such as structure similarity retrieving as well as a structure and component representation.

To address these limitations, the objective of this study is to develop a modular product design retrieval system that can search similar designs based on different level of similarity.

To accomplish this objective, a unified indexing scheme is proposed. Using an *S* matrix as a unified indexing scheme is an excellent way to achieve an application of modular design retrieval because:

- It establishes a uniform indexing method with a unique representation of a specific view for a modular product.
- It embeds all modular structure information as well as all components in one representation.

A fuzzy neural network is then utilized as a retrieval mechanism for searching similar designs. The reason for utilizing Fuzzy-ART neural network is that it can tolerate incomplete query and still find most similar designs. Furthermore, a user can retrieve not only similar structural products based on a similarity level for the purpose of conceptual design, but a user can reference similar modular products within his or her organization for business purposes. Moreover, a designer is able to control the similarity of retrieved designs by adjusting the similarity level of the Fuzzy-ART neural network. Additionally, the embedding of proposed method with existing databases is developed in order to enable the retrieval system to be able to be implemented with any existing databases.

CHAPTER 4

A PLATFORM FOR WEB-BASED MODULAR RETRIEVAL AND IMPLEMENTATION

4.1. Web-based modular product retrieval platform

In recent years, the need for an Internet-based information system framework has become essential. An enterprise strongly looks for an effective tool to manage and manipulate the flow of information among participating businesses. E-commerce has become common in the manufacturing industry. With shorter development and manufacturing lead-times, the competitiveness and profitability of an enterprise can be increased tremendously. In order to eliminate problems both with communication and data-incompatibility formatting, a framework is needed to exchange data between design and manufacturing users in different product-development work environments (Chao and Wang, 2001). This framework should consist of a client database, an index server, a design data format translator, and a file-sharing control module.

With the great technology of the Internet and the World Wide Web, a variety of Web-based applications have been developed and implemented in product design and manufacturing, yet more will become accessible in the future. As one can see from efforts in these Web-based applications, Web technology is accepted as a highly adequate information infrastructure for providing collaboration among organizations.

As a result, Web-based application has become a new highway of communication among customers and enterprises in manufacturing environments. It enables agile manufacturers to promptly communicate with customer demands by eliminating integration barriers. Customers are able now to rapidly customize their product via Web-based applications. Past studies have covered several main areas of Web applications. However, manufacturing-specific search engines to support the utilization of Web applications in product design and manufacturing have yet to be developed.

Generally, successful product design retrieval tasks need to be achieved through integrating and utilizing all kinds of knowledge from various sources. Accordingly, Web technology not only enhances product design and manufacturing, but also serves as an important medium for technology transfer. Web technology has exploded over the last decades. Manufacturing enterprises are moving toward this popular and visible technology. Numerous Web-based applications are found in the manufacturing environment in areas such as quotation and order processing, design for manufacture and assembly, process and production planning, and production and inventory control. (Huang and Mak, 2001a). Some studies have implemented Web-technology within their models. Huang (2002) presented a Web-based framework for supporting collaborative product design review between partners in the extended enterprise. The system will help to enable a more efficient and effective design review system in the process of new product development.

Liu and Xu (2001) reviewed the integration of product data management methodology with Web architecture and showed how Web technologies enhance a traditional product data management system. If both Web technology and product data management are integrated properly, they will enhance each other's capabilities and performance. However, Liu and Xu face issues such as not-large-enough bandwidth, as well as issues with the security of the information flow between a company and its suppliers. Huang and Mak (2000) developed a methodology to enable better supplier involvement in new product development process through a prototype Web-based platform.

Wang, Chu, and Yin (2001) addressed the two prominent issues in remote manufacturing. The authors described a practical situation in which robotic manufacturing includes remote manufacturing. An integrated product data model and related configuration were proposed. To execute a variety of manufacturing functions and in order to manipulate product data, a hybrid architecture of Web/server and client/server was proposed. The authors concluded by proposing a CORBA standards-based integration framework to address problems regarding interoperability with multiple data and application objects over the Internet, as well as over company intranets.

4.1.1. Modular product retrieval by customer needs

In order to meet the needs of customers, we must embrace an environment where they can individually demand customized products. However, customer needs are expressed in many complicated ways, because they often are determined in imprecise, nontechnical terms and in qualitative (rather than quantitative) language. The essential process of translating customer needs into useful design specifications can be shared easily between members of an organization (Harding, *et al*. 2001). The translation of customer needs enables us to interpret raw, imprecise market information into clearly defined design requirements.

Customer needs initially generate conceptual product functional requirements. Furthermore, typical product information includes a product structure and a functional architecture that are interrelated through mapping from functions to components. Although product structure resembles that of physical components, in many situations we would like to communicate with the customer in terms of the customer's own view or a functionality-oriented view of configurable products. Products are viewed therefore in terms of functionality or features that can be offered to and selected by the customer. Consequently, the product can be described through functions that can again be embodied by components.

Traditionally, product databases have contained only product components and information. It is difficult to retrieve a reference product design using only functional requirements as query input. As a result, the need for functional requirements to be associated with design parameters and physical components is commonly stated. These functional requirements have been determined to satisfy the customer needs.

According to Suh (1998), therefore, the concept of a product functional requirement may be divided into subproblems by decomposition. One approach to problem decomposition is to use modularity. Once the customer requirements have been determined, the product design can begin and design characteristics that satisfy the customer requirements may be established. The techniques adopted for presenting and analyzing the quality of the product are based on Quality Function Deployment (QFD).

QFD is utilized in this framework as a procedure to incorporate customer needs into a modular product retrieval system. Also, QFD is a method of mapping the needs of the customer to the features and functions of the product. QFD is a systematic approach by which customers' requirements are translated into engineering specifications. It is a well-established, comprehensive quality system, which targets satisfaction of customer needs as a mean of improving product quality.

A tool that has been used primarily in QFD is a matrix called House of Quality (HoQ; Houser and Clausing, 1988). According to HoQ, we can present customer needs using the HoQ model, as shown in Figure 4.1. Then the customers' needs are listed and are translated into product features and functions or into design requirements.

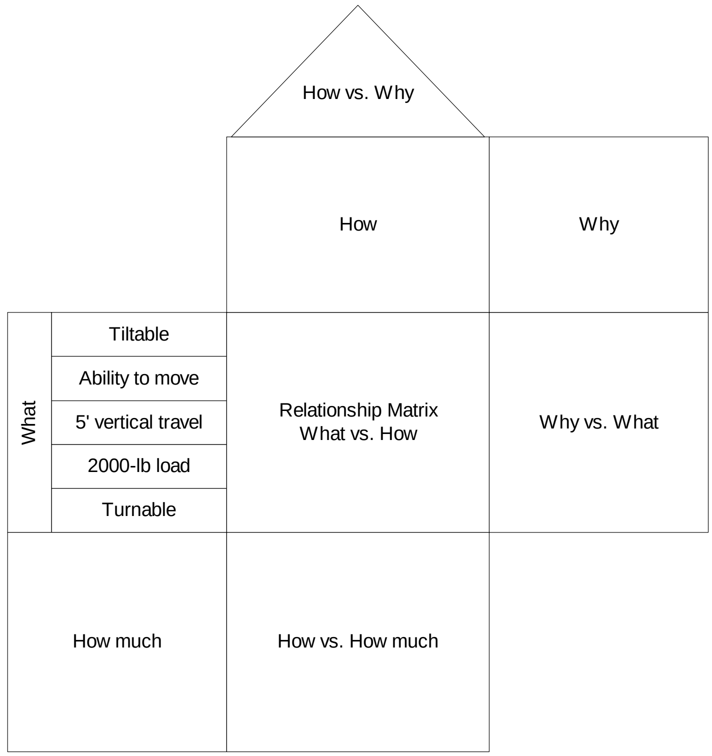


Figure 4.1. House of Quality for a lift product

Once the requirement in the matrix is determined, the rankings for absolute and relative importance can be calculated. In the HoQ model, the absolute weight is used to make the design decision by comparing and ranking the weight value of each design alternative. The absolute weights of each FR can be calculated by multiplying each correlation by its corresponding demand weight and the total.

After analyzing the system input requirements and ranking the priority of each design alternative, the system can extract the recommended design alternatives based on the higher absolute weight. By composing all design parameters, we then have a new conceptual design.

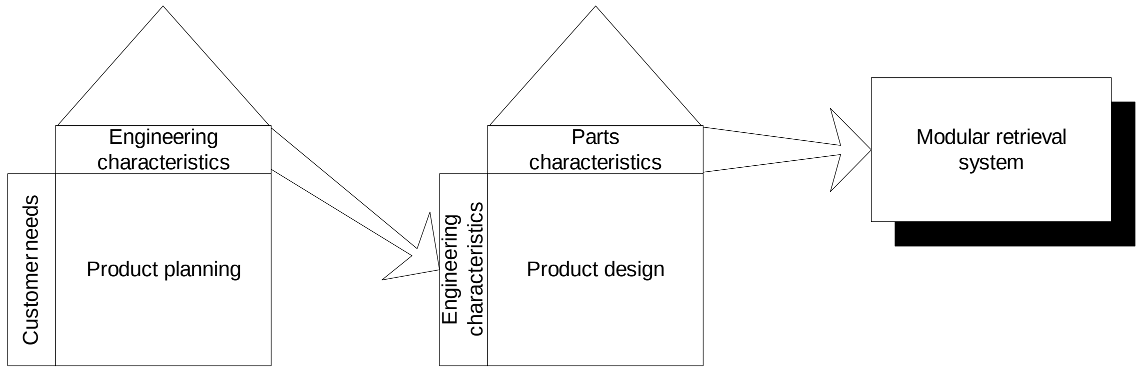


Figure 4.2. QFD framework to module-based product retrieval system

Once a conceptual design is determined, we then introduce this conceptual design to the proposed method using a unified indexing scheme. Therefore, we can transform the functional requirement into required components and/or required product modules by using QFD. After QFD determines a possible solution of a new conceptual product design, we can use the information as a query for our proposed modular product retrieval system.

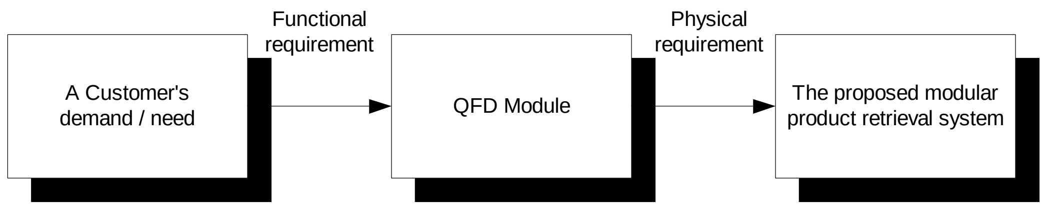


Figure 4.3. Information flow from functional to physical

4.1.2. Web-based technology

Even if the gap between designers and product design development is bridged successfully, customer requirements may be lost in the implementation. The integration of the application system has to be supported on an architectural level throughout the process, from customer needs to finished products. Therefore, using Web-based technology is seen as the ideal method to improve efficiency by eliminating integration barriers between customers and manufacturers. Customers are able to determine their needs and retrieve products they want.

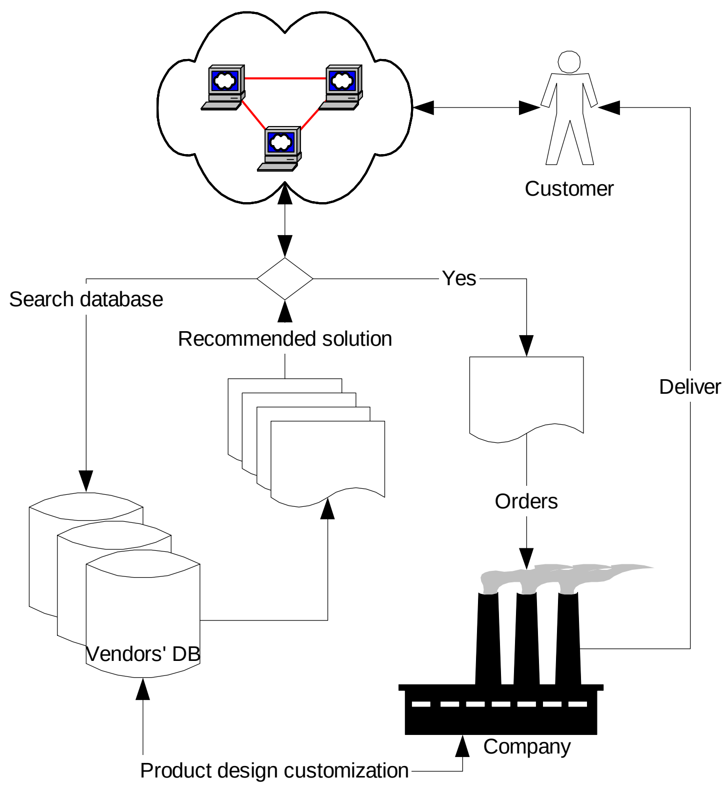


Figure 4.4. Web-based ordering system

The Web-based technology can be applied by following a client-server architecture, because it inherits most features of client-server distributed computing. The Internet has given rise to retrieval system technologies that are used today to publish database applications on the Internet and on private intranets. Three-tier architecture is used for this modular product retrieval system; three types of tiers are shown in Figure 4.5. They are: the database server, the Web server, and the browsers or client computers.

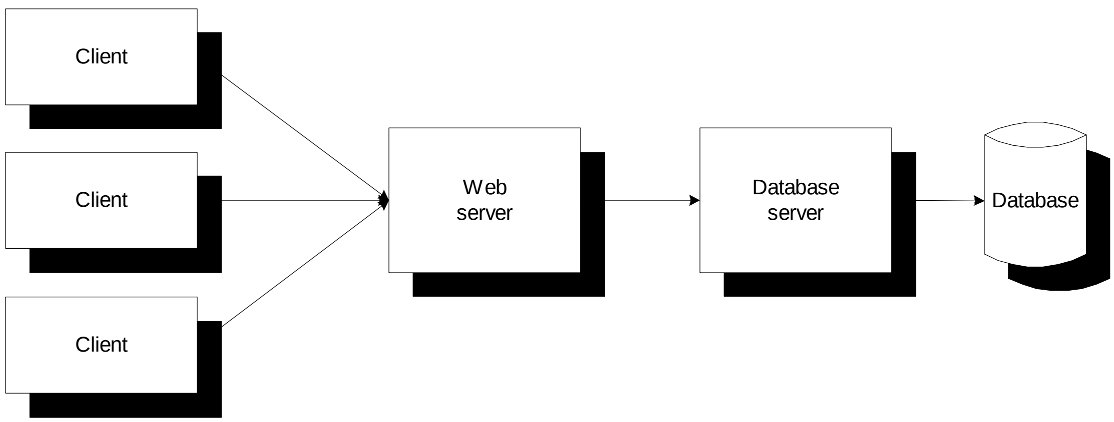


Figure 4.5. A three-tier architecture

The environment in which today's Internet technology database applications reside is rich and complicated. The retrieval system should have the ability to achieve a Web-based interface retrieval system environment, which should address the delay of product development due to the lack of instant information exchange. In essence, this Web-based retrieval system also provides the much-needed instant communication between vendors, suppliers, manufacturers, and customers, which will affect the speed at which products are developed. With all three corollaries and Web technology, we can conclude the Web-based platform shown in Figure 4.6.

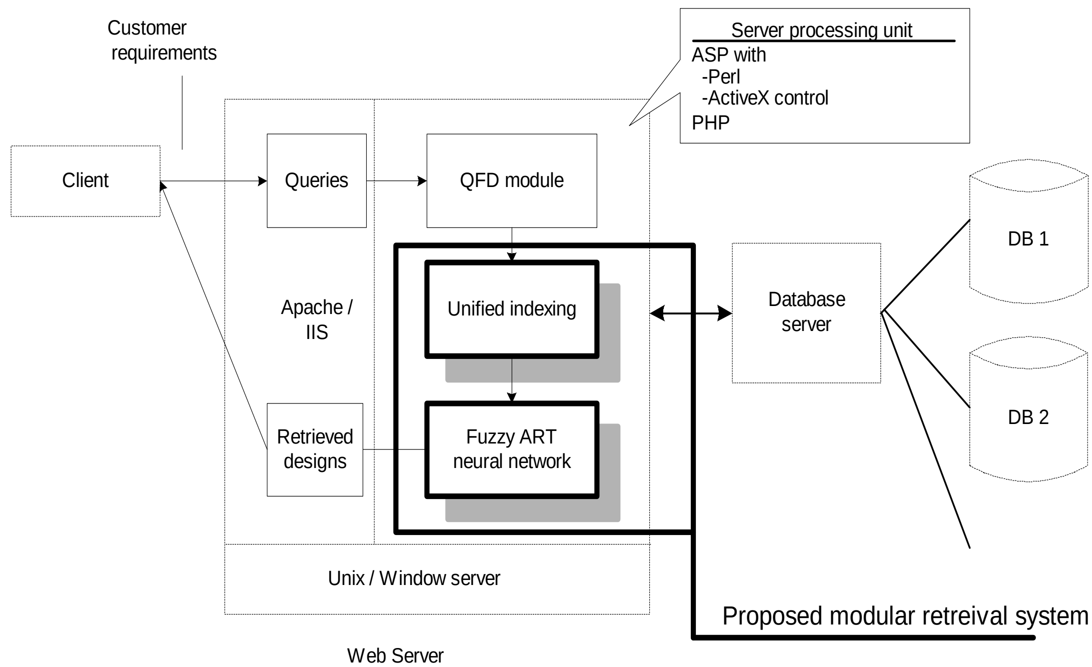


Figure 4.6. Proposed platform for Web-based modular product retrieval system

The goal of this research is to develop a computer-aided system that assists designers in improving the conceptual design process, by employing modular product design. As stated in the preceding problem statements, there are several difficulties found in current modular product design technology. Therefore, the aim is to develop a system that enables more effective product design retrieval and to propose a framework to facilitate a Web-based platform. This platform for modular retrieval system would have the ability to achieve an Internet-based interface retrieval system, which would facilitate e-commerce environment.

4.2. Web-based modular product retrieval system architecture

In order to accomplish the fundamentals imposed by a Web-based modular product retrieval system, the system is designed for and is implemented in a PC environment with any Internet browser. The system has an interactive interface, which allows users to make queries and retrieve product data. The system is connected with a database that can be updated under restricted circumstances. As seen in Figure 4.5, we consider this Web-based system architecture to contain the following modules: (1) database module; (2) user-interface module; and (3) product-retrieval module.

Database module: The objective of this module is to store all the information needed for product retrieval. A company has full access privileges to this module without any restrictions in order to perform insertion, deletion, or update operations. However, the user has limited access to this module, and can retrieve information only.

User-interface module: The objective of this module is to create a front office for a company. It usually is the Web-site of the company and serves as the company's representative to the user or to a customer. A user can perform tasks such as product- or part-information retrieval based on product identification, or part identification. Furthermore, a user can search product designs based on product similarity. Moreover, in this module, a user can query a conceptual product design or can request information on a product design with incomplete information. Also, the user can search a product design, as well as its components and corresponding information such as price, inventory, or suppliers.

Product retrieval module: The objective of this module is to form a bridge between user and database. This module is based on our proposed unified indexing and Fuzzy-ART neural network retrieving algorithm. Through this module, a user's query is received and implemented with a unified indexing method and is used as an input for Fuzzy-ART neural network retrieving. Retrieved designs then are sent back to the user and the system is ready to perform a new task.

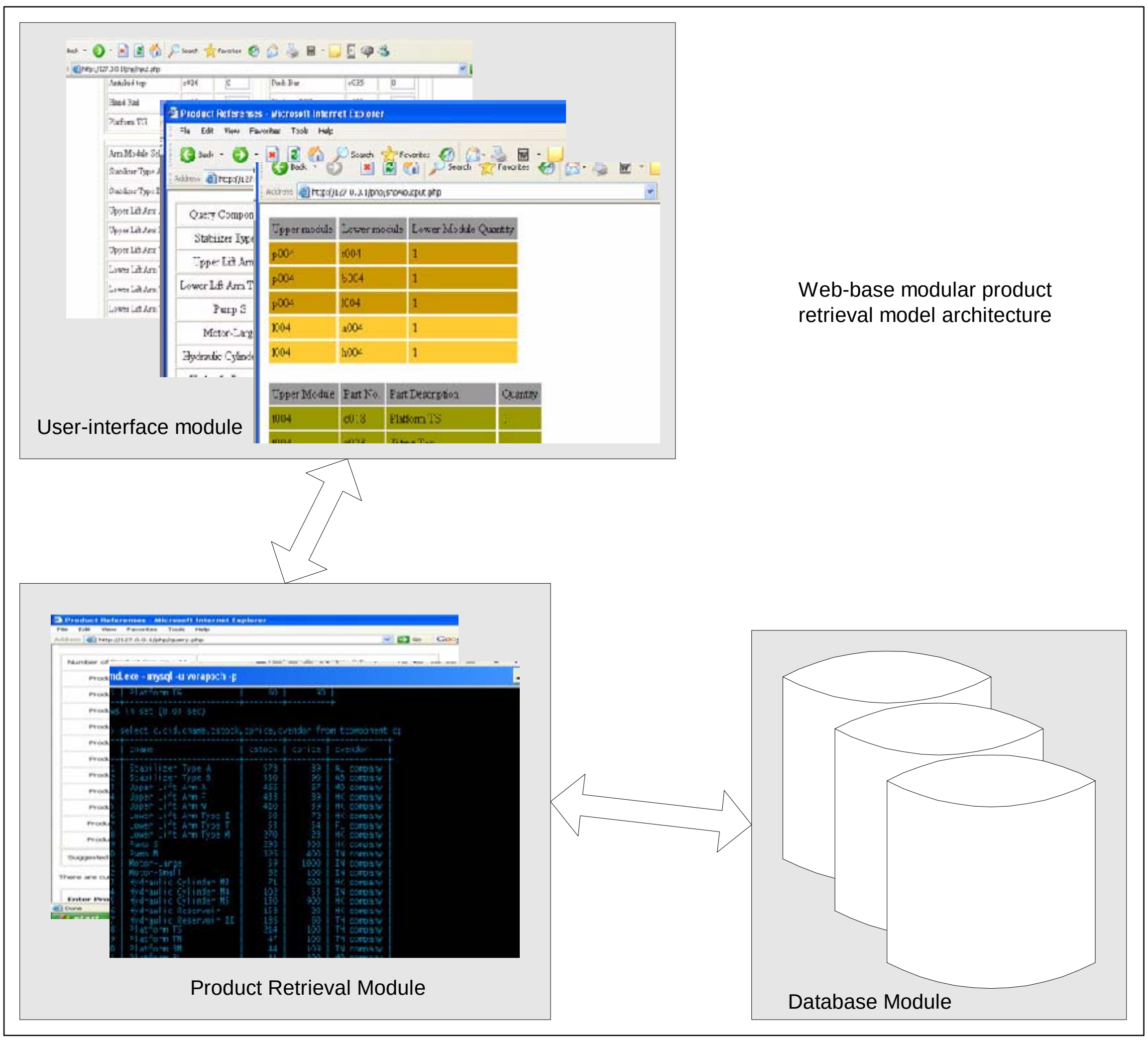


Figure 4.7. Web-base modular product retrieval model architecture

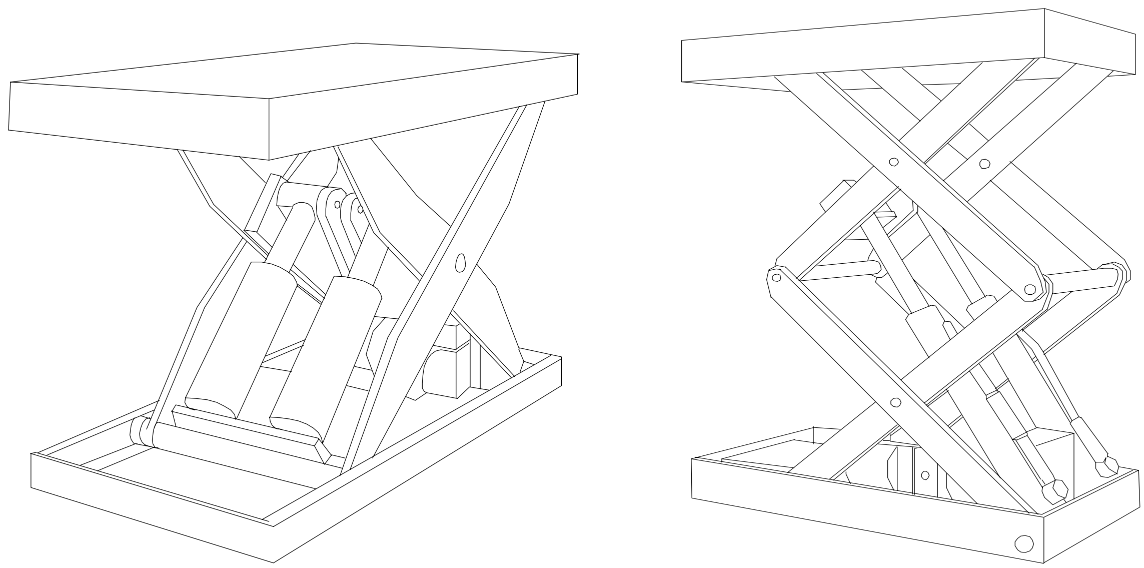
In the next section, we present an implementation through a Web-based platform for our proposed method for a modular product retrieval system. This approach to the platform integrates all interactions from customer to manufacturer. A user is able to select desired components of a new conceptual design.

4.3. Web-based modular product retrieval system implementation

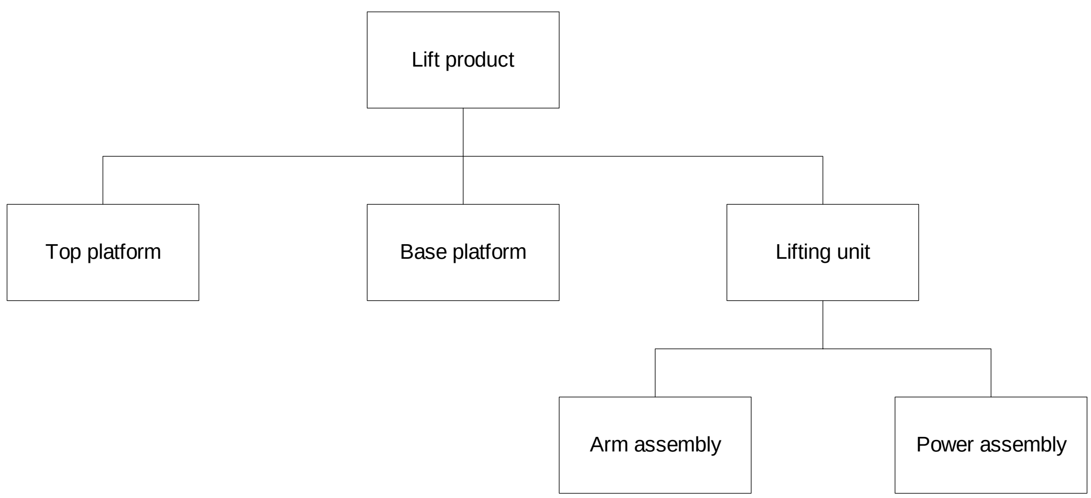
A Web-based modular product retrieval system implementation is composed of the three different modules described above. The retrieval system has been developed using HTML, PHP scripting language, SQL database language, an Apache Web server and an MySQL database server. PHP and SQL are used as scripting implementation on an Apache Web server and interact with the MySQL database server. Thus, a user is able to select desired components of a new conceptual design. The information is then sent through the Internet and the command will be executed by the server side.

4.3.1. Database module

For illustration purposes, a lift product database will be used as a database module. In one view, its structure can be decomposed to three major modules, as shown in Figure 4.8. It consists of a top platform module, a bottom platform module, and a lifting module. The lifting module is composed of two other units, the arm module and the power module. The numbers of required components corresponding to each module are shown in Appendix B. To demonstrate the ability to retrieve reference designs based on structure and on components similarity to a relational database, we implement Corollary 3 with a database and use our proposed retrieval algorithm to do the tasks.



(a)



(b)

Figure 4.8. (a) Sample of Lift products; (b) Lift structure view

The database module stores all information related to product and component information such as price and inventory. A relational database is performed as a set of tables. An example of a relational instance in a database module is a set of records in which each record has the same number of fields as the relation schema. A relational instance can be thought of as a table in which each record is a row and all rows have the same number of fields. Moreover, a common product design and its components can be considered as a record in a database. The conceptual database design, E-R diagram, for this lift product database is shown in Figure 4.9.

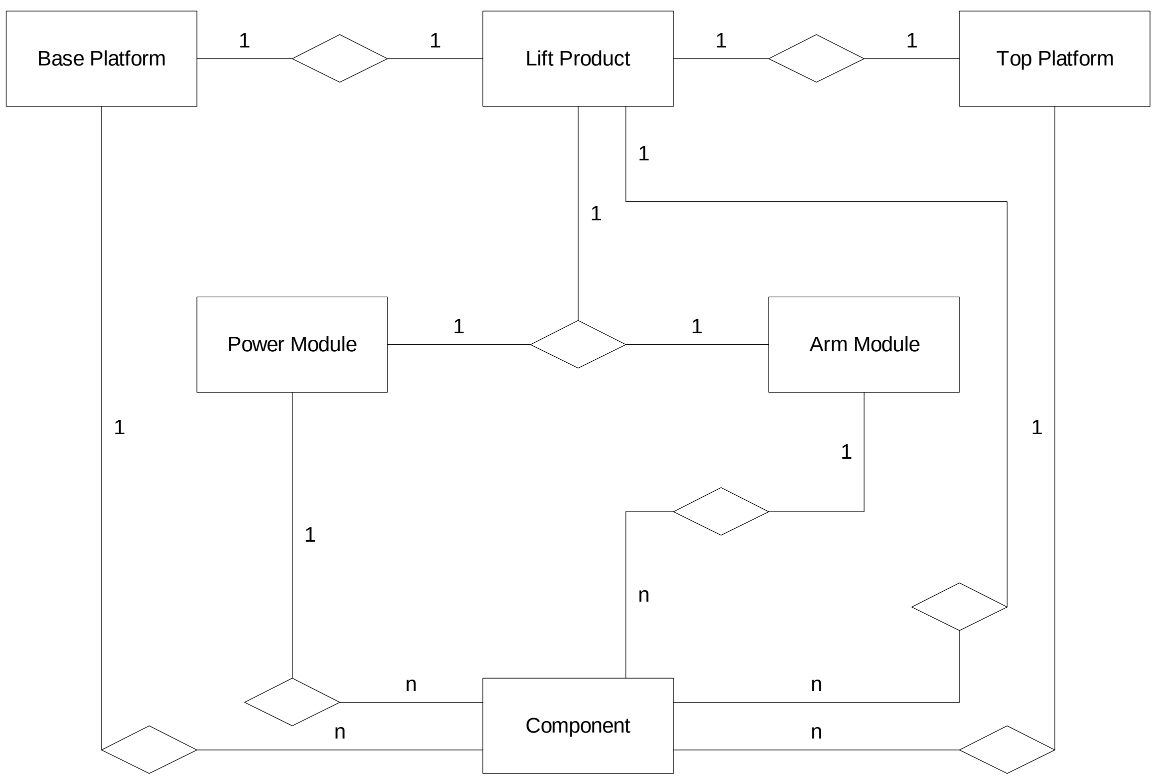
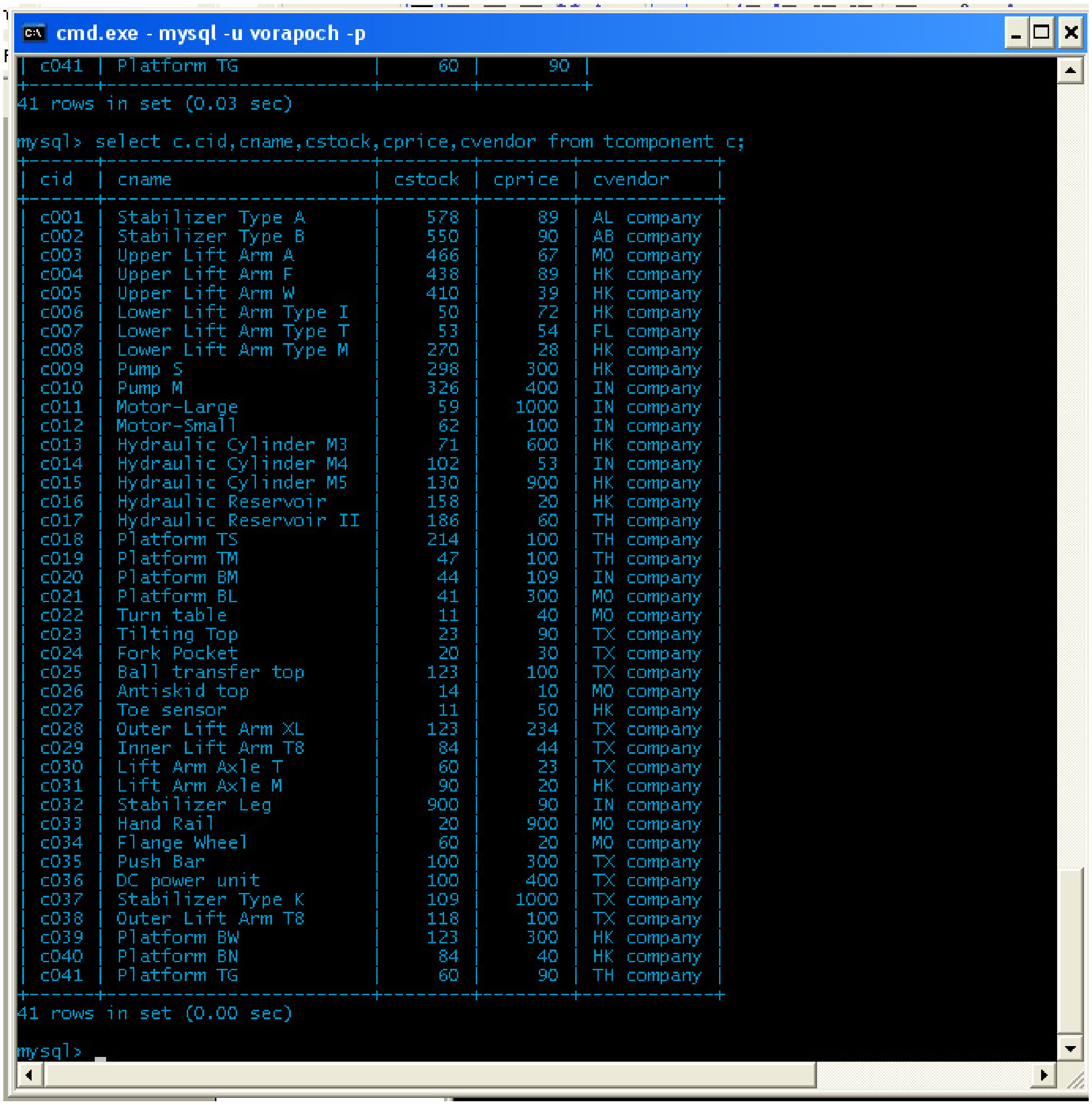


Figure 4.9. A conceptual E-R diagram of a lift database

The database module provides a company with the ability to perform a database operation such as insertion, deletion, or update without any restrictions. A company directly accesses the database module (Figure 4.10) without having to first access the user-interface module.


```
cmd.exe - mysql -u vorapoch -p
| c041 | Platform TG                  |     60 |      90 |
+------+------------------------------+--------+---------+
41 rows in set (0.03 sec)

mysql> select c.cid,cname,cstock,cprice,cvendor from tcomponent c;
+------+------------------------------+--------+---------+------------+
| cid  | cname                        | cstock | cprice  | cvendor    |
+------+------------------------------+--------+---------+------------+
| c001 | Stabilizer Type A            |    578 |      89 | AL company |
| c002 | Stabilizer Type B            |    550 |      90 | AB company |
| c003 | Upper Lift Arm A             |    466 |      67 | MO company |
| c004 | Upper Lift Arm F             |    438 |      89 | HK company |
| c005 | Upper Lift Arm W             |    410 |      39 | HK company |
| c006 | Lower Lift Arm Type I        |     50 |      72 | HK company |
| c007 | Lower Lift Arm Type T        |     53 |      54 | FL company |
| c008 | Lower Lift Arm Type M        |    270 |      28 | HK company |
| c009 | Pump S                       |    298 |     300 | HK company |
| c010 | Pump M                       |    326 |     400 | IN company |
| c011 | Motor-Large                  |     59 |    1000 | IN company |
| c012 | Motor-Small                  |     62 |     100 | IN company |
| c013 | Hydraulic Cylinder M3        |     71 |     600 | HK company |
| c014 | Hydraulic Cylinder M4        |    102 |      53 | IN company |
| c015 | Hydraulic Cylinder M5        |    130 |     900 | HK company |
| c016 | Hydraulic Reservoir          |    158 |      20 | HK company |
| c017 | Hydraulic Reservoir II       |    186 |      60 | TH company |
| c018 | Platform TS                  |    214 |     100 | TH company |
| c019 | Platform TM                  |     47 |     100 | TH company |
| c020 | Platform BM                  |     44 |     109 | IN company |
| c021 | Platform BL                  |     41 |     300 | MO company |
| c022 | Turn table                   |     11 |      40 | MO company |
| c023 | Tilting Top                  |     23 |      90 | TX company |
| c024 | Fork Pocket                  |     20 |      30 | TX company |
| c025 | Ball transfer top            |    123 |     100 | TX company |
| c026 | Antiskid top                 |     14 |      10 | MO company |
| c027 | Toe sensor                   |     11 |      50 | HK company |
| c028 | Outer Lift Arm XL            |    123 |     234 | TX company |
| c029 | Inner Lift Arm T8            |     84 |      44 | TX company |
| c030 | Lift Arm Axle T              |     60 |      23 | TX company |
| c031 | Lift Arm Axle M              |     90 |      20 | HK company |
| c032 | Stabilizer Leg               |    900 |      90 | IN company |
| c033 | Hand Rail                    |     20 |     900 | MO company |
| c034 | Flange Wheel                 |     60 |      20 | MO company |
| c035 | Push Bar                     |    100 |     300 | TX company |
| c036 | DC power unit                |    100 |     400 | TX company |
| c037 | Stabilizer Type K            |    109 |    1000 | TX company |
| c038 | Outer Lift Arm T8            |    118 |     100 | TX company |
| c039 | Platform BW                  |    123 |     300 | HK company |
| c040 | Platform BN                  |     84 |      40 | HK company |
| c041 | Platform TG                  |     60 |      90 | TH company |
+------+------------------------------+--------+---------+------------+
41 rows in set (0.00 sec)

mysql>
```

Figure 4.10. Accessing list of components from MySQL database server

4.3.2. User-interface module

The user-interface module serves as a company representative that, ideally, is the company's Web site. It is created to provide the user with an interactive modular product retrieval system. The user-interface module also is utilized to exchange information between the user and the company, so that a user can rapidly retrieve similar designs based on their preference. Not only does the user have the ability to retrieve products based on product identification (i.e., product identification number or product name), but the user also has the ability to retrieve similar designs without necessarily having complete information for a query.

According to the database tables in Appendix C, a user can generate a next assembly and quantity information table for Product No. 25 by using a product identification number for retrieval, as shown in Figure 4.11.

Product No. 25

Retail Price: USD 4100.00   Inventory: 56

Upper module	Lower module	Lower Module Quantity
p025	t002	1
p025	b001	1
p025	l010	1
l010	a009	1
l010	h006	1

Upper Module	Part No.	Part Description	Quantity
t002	c019	Platform TM	1
t002	c025	Ball transfer top	1
b001	c021	Platform BL	1
a009	c003	Upper Lift Arm A	4
a009	c008	Lower Lift Arm Type M	4
a009	c031	Lift Arm Axle M	2
a009	c037	Stabilizer Type K	4
h006	c010	Pump M	1
h006	c012	Motor-Small	1
h006	c015	Hydraulic Cylinder M5	2
h006	c017	Hydraulic Reservoir II	1

Figure 4.11. Product/modules and components relationships

However, the user is not limited only to retrieving a product design based on product identification number. Alternatively, to retrieve reference modular products based on structural similarity, the user need only enter the number of quantity of each component of each module on a query page (Figure 4.12), on the Web site. Component and module listings on the Web site are dynamically connected to the database module, where they are updated in real-time by the company. The user-interface module then takes the query from the user and passes it to the product-retrieval module.

4.3.3. Product-retrieval module

Every time a user queries from the user-interface module, this module generates information, then interfaces with the database module. A query is compared to several different design databases in the database module.

By using Fuzzy-ART as a retrieval algorithm, this module generates a similar product reference list based on user input. Retrieved designs are sent back to a user browser for further review. The proposed unified indexing scheme is implemented to the N matrix above. Using a unified indexing scheme, we can obtain a component and structural matrix, S, from the N matrix as follows:

$$S_i = (I - N_i)^{-1} - I$$

Therefore, the embedding of the proposed method has been developed to enable the retrieval system to be implemented with any existing databases. A fuzzy neural network then is utilized as a retrieval mechanism for searching similar designs. Moreover, a user is able to control the similarity of retrieved designs by adjusting the similarity level of the Fuzzy-ART neural network. Once a retrieval task has been done, the retrieval module will return information of the retrieved product design (Figure 4.14), to the user via the user-interface module for further review.

4.4. Validation of module-based product retrieval system

Upon completion of the Web-base modular product retrieval system implementation, retrieval tasks were performed in order to demonstrate the benefit of using Fuzzy-ART neural network as a retrieval algorithm with Web technology.

4.4.1. Validation 1: Search result with complete product information

To validate the Fuzzy-ART retrieval mechanism, complete information of a modular product was used as a query input. By adjusting the similarity level for Fuzzy-ART neural networks, the user can set preferences for retrieving similar product designs. The list of retrieved product designs using Product No. 25 as a validation is shown in Table 4.1. Table 4.1 shows retrieved products when the user performs a search at different similarity levels.

Using Product No. 25 as an example of a user's input, the retrieval module will generate a proposed unified indexing matrix. Because N_i is a next assembly relationship, the information from Figure 4.12 then can be represented in numerical form as the next assembly quantity matrix. The next component assembly matrix for Product No. 25 is shown in Figure 4.13:

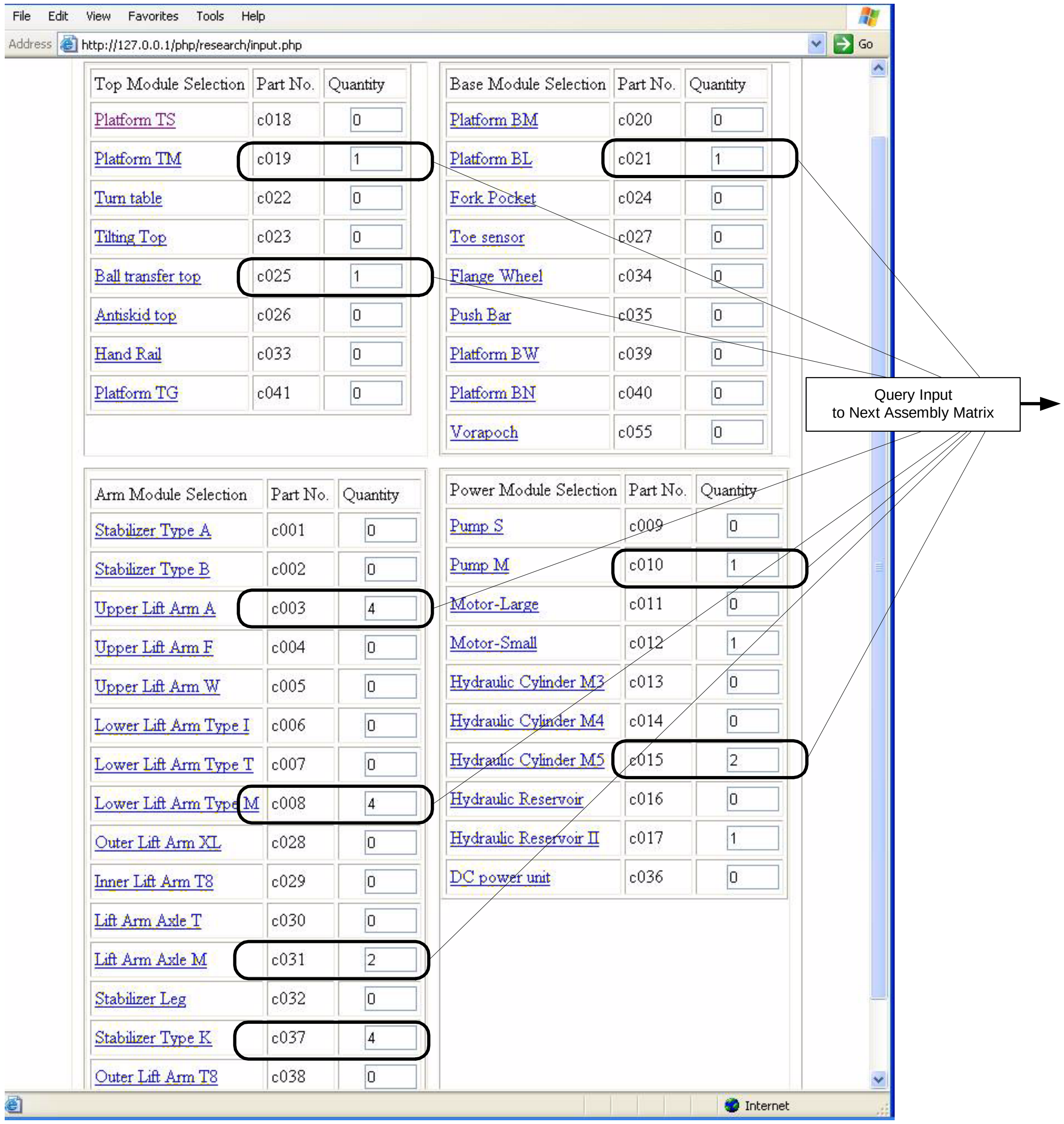


Figure 4.12. Query input of Product No. 25

$$
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{matrix}
0 \\ T \\ B \\ L \\ H \\ A \\ c003 \\ c008 \\ c010 \\ c012 \\ c015 \\ c017 \\ c019 \\ c021 \\ c025 \\ c031 \\ c037
\end{matrix}
$$

Figure 4.13. Next assembly, N_{p025}, information

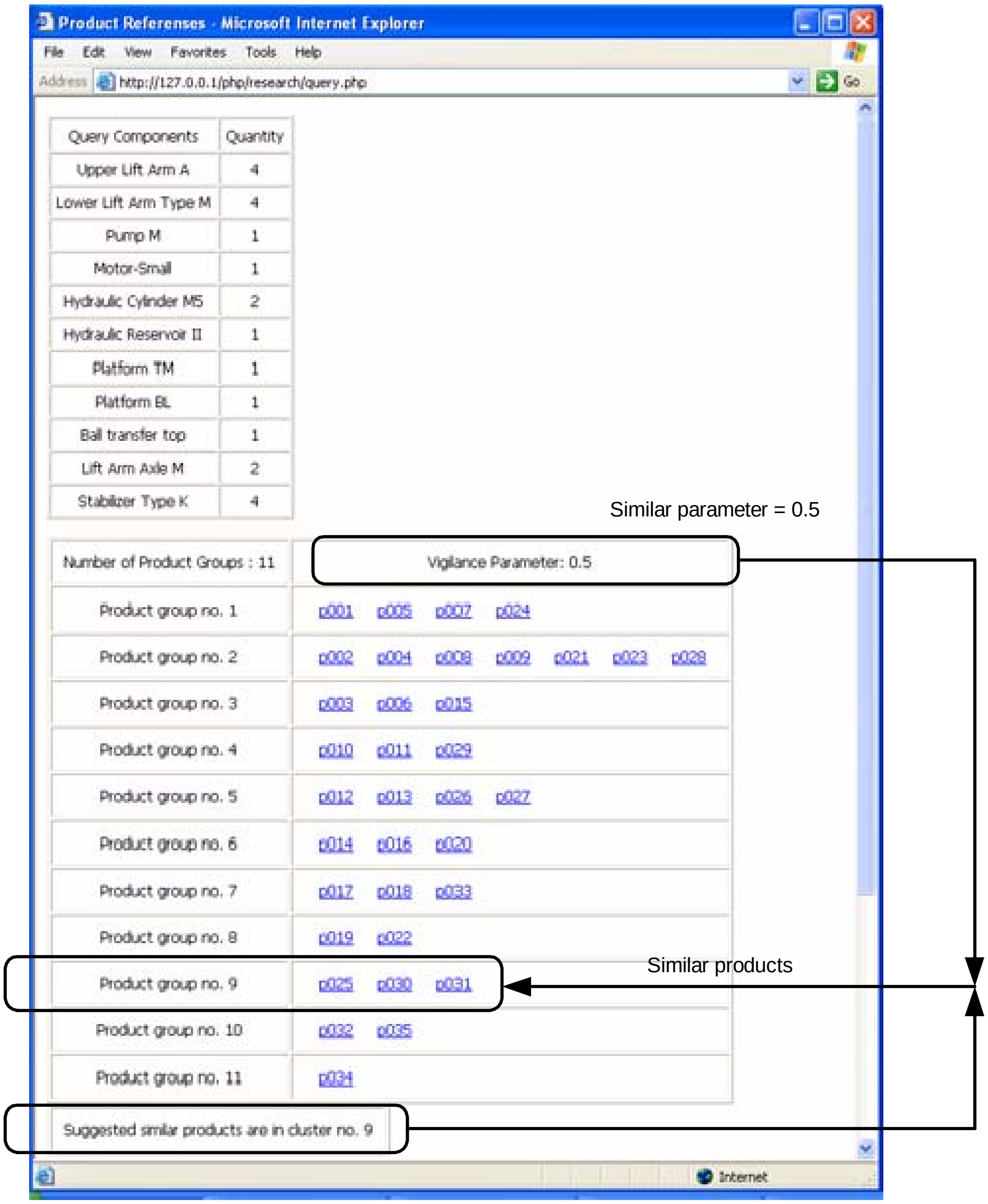


Figure 4.14. Retrieved similar design results

Similarity Level	Retrieved Product No.
0.5	**25**, 30, 31

Table 4.1. Retrieved product designs at similarity level of 0.5

Correspondingly, at the following similarity level, 0.3, 0.7, and 0.9, the retrieved products for each level include Product No. 25. This concludes that the retrieval algorithm is effective in searching of exact same product design.

Similarity Level	Retrieved Product No.
0.3	3, 6, 10, 11, 12, 15, 17, 19, 22, **25**
0.5	**25**, 30, 31
0.7	**25**, 30
0.9	**25**

Table 4.2. Retrieved product designs at different similarity levels

4.4.2. Validation 2: Search result with incomplete product information

As a second illustration, suppose that a user plans to develop a new lift product and needs to retrieve similar products from vendors' databases. However, the user has only partial information about the product. Because a Fuzzy-ART neural network operates in an associative way, it is able to tolerate and incorporate an incomplete query and still able to find most similar reference designs. By adjusting the similarity parameter of the network, designers may adjust the similarity of retrieved reference designs. Table 4.3 shows the list of retrieved product designs derived by omitting some components of the Product No. 33, to illustrate a search conducted with incomplete information.

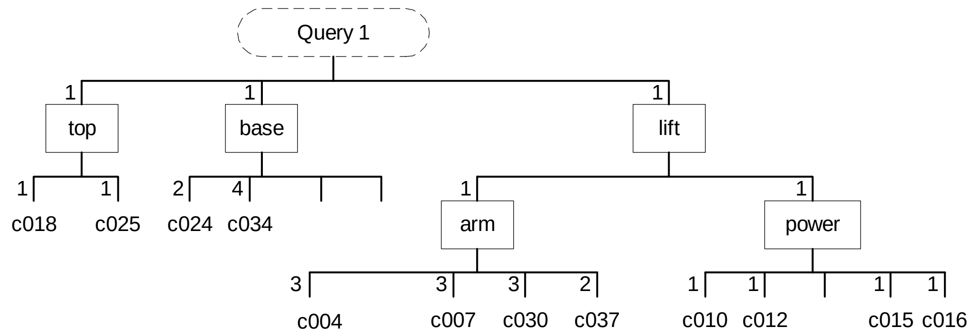


Figure 4.15. Query No. 1 component and structure information

Similarity Level	Retrieved Products No.
0.3	3, 6, 10, 11, 12, 15, 17, 19, 22, 25, 29, **33**
0.5	17, 18, **33**
0.7	17, **33**
0.9	**33**

Table 4.3. Retrieved product designs with incomplete information

Even though the user cannot provide a query that is perfectly relevant to the target products, the retrieval system is still effective enough to retrieve possible similar products. For similarity level 0.5, similar products are shown as the following Figure 4.16.

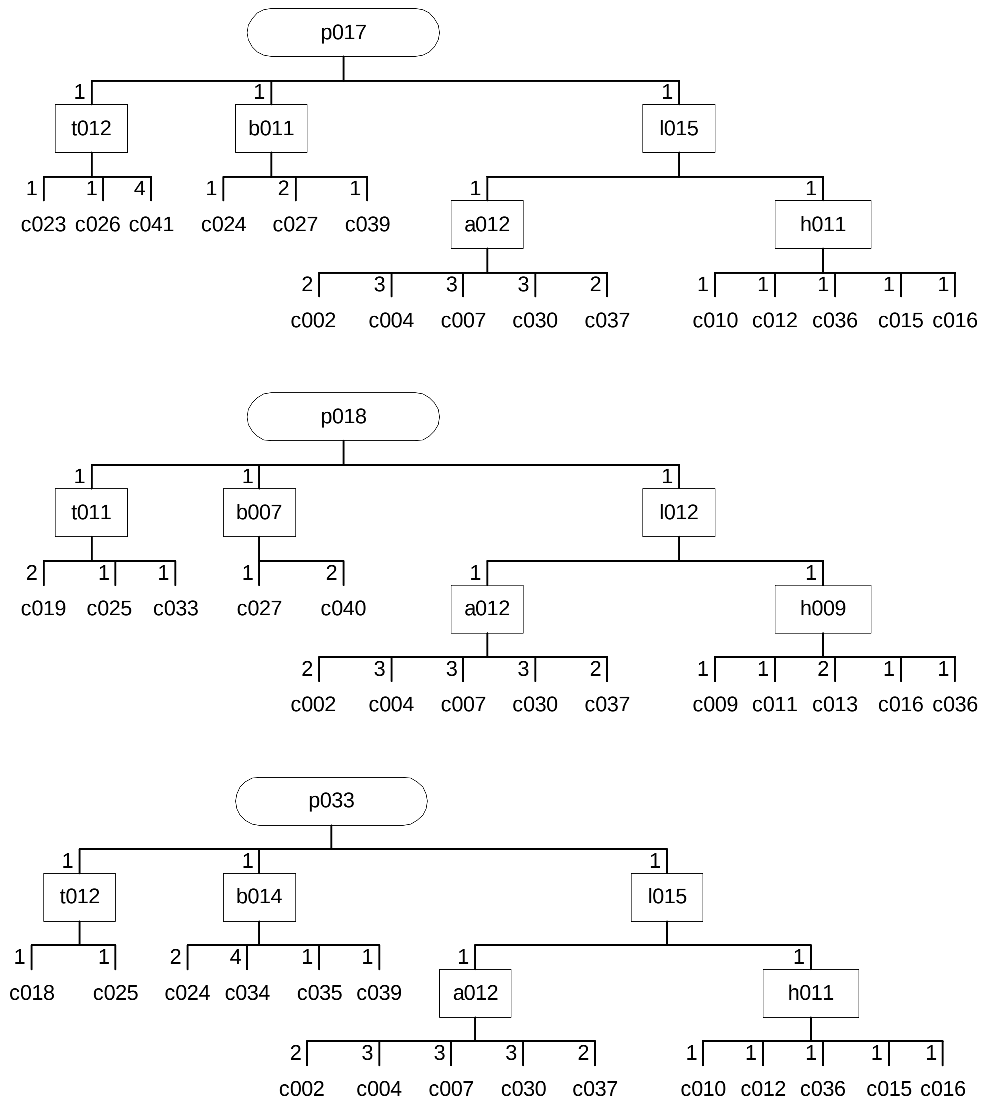


Figure 4.16. Similar products with incomplete information of Product No. 33

at similarity level 0.5

4.4.3. Validation 3: Search result with highly incomplete product information

As a third illustration, suppose that a user plans to develop a new lift product and needs to retrieve similar products from vendors' databases. However, the user has only partial information about the product. Table 4.4 shows the list of retrieved product designs derived by omitting *most* components of the Product No. 33, to illustrate a search conducted with highly incomplete information. The users can search at lower similarity level as a *"weak"* similarity

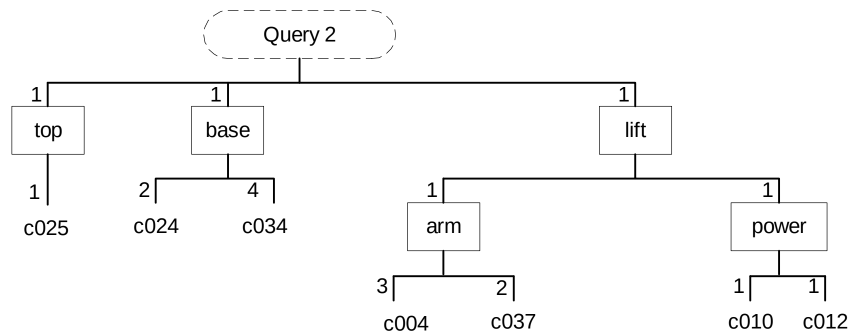


Figure 4.17. Query No. 2 component and structure information

Similarity Level	Retrieved Product No.
0.3	3, 6, 10, 11, 12, 15, 17, 19, 22, 25, 29, **33**
0.5	3, 6, 15, 10, 11, 29
0.7	17, **33**
0.9	**33**

Table 4.4. Retrieved product designs with highly incomplete information

As previously mentioned, the user cannot provide a query that is perfectly relevant to target products. This retrieval system should be effective enough to retrieve possible similar products based on component and structure. From Table 4.4, even though most of components are omitted from Product No. 33, the proposed system is still able to retrieve similar products. However, at similarity level 0.5, the system will retrieve a group of similar products that does not include Product No. 33. The reason for this is that Fuzzy-ART neural network can tolerate a certain degree of incomplete query. However, if a query is missing too much information, the search result may not be relevant.

In addition, the proposed Fuzzy-ART retrieval system give us the ability to retrieve a group of similar products at a lower similarity level, while other retrieval systems may only tell us the value of dissimilarity.

4.5. Implementation of reference retrieval for new conceptual designs

The implementation of the proposed method is carried out as part of a modular product design retrieval system. By adjusting the similarity parameter of the network, designers may adjust the similarity of retrieved reference designs. The following shows cases of retrieved product designs to illustrate a search conducted in this study.

4.5.1. Case 1: A conceptual design with existing information

To demonstrate the work, assume that users want to roughly search products that are similar to the Conceptual Design 1 with existing component information. Reference products can be propagated from a Fuzzy-ART neural network when design databases, a design query, and a similarity parameter are specified. Therefore, by adjusting the similarity parameter inside the Fuzzy-ART neural network, designers can get variant numbers of similar products. Table 4.5. shows the list of retrieved product designs for the Conceptual Design 1.

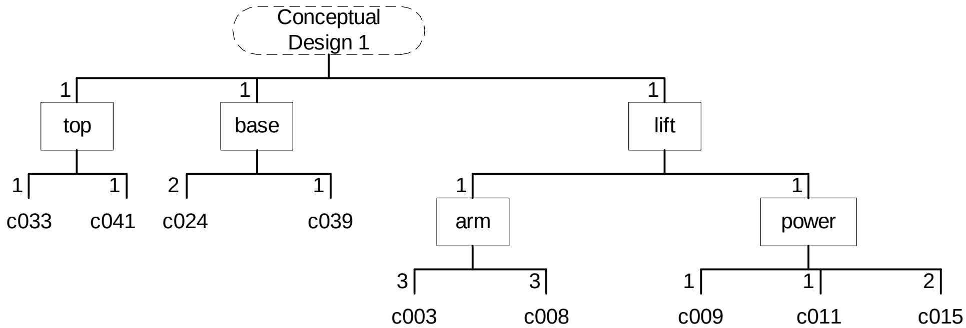


Figure 4.18. Conceptual Design 1's component and structure information

Similarity Level	Retrieved Product No.
0.3	1, 2, 4, 5, 7, 8, 9, 14, 16, 20, 21, 23, 24, 28, 30, 31, 32, 34, 35
0.5	4, 9, 21, 23, 28
0.7	None

Table 4.5. Retrieved product designs for Conceptual Design 1

For similarity level 0.5, similar products are shown as the following Figure 4.19.

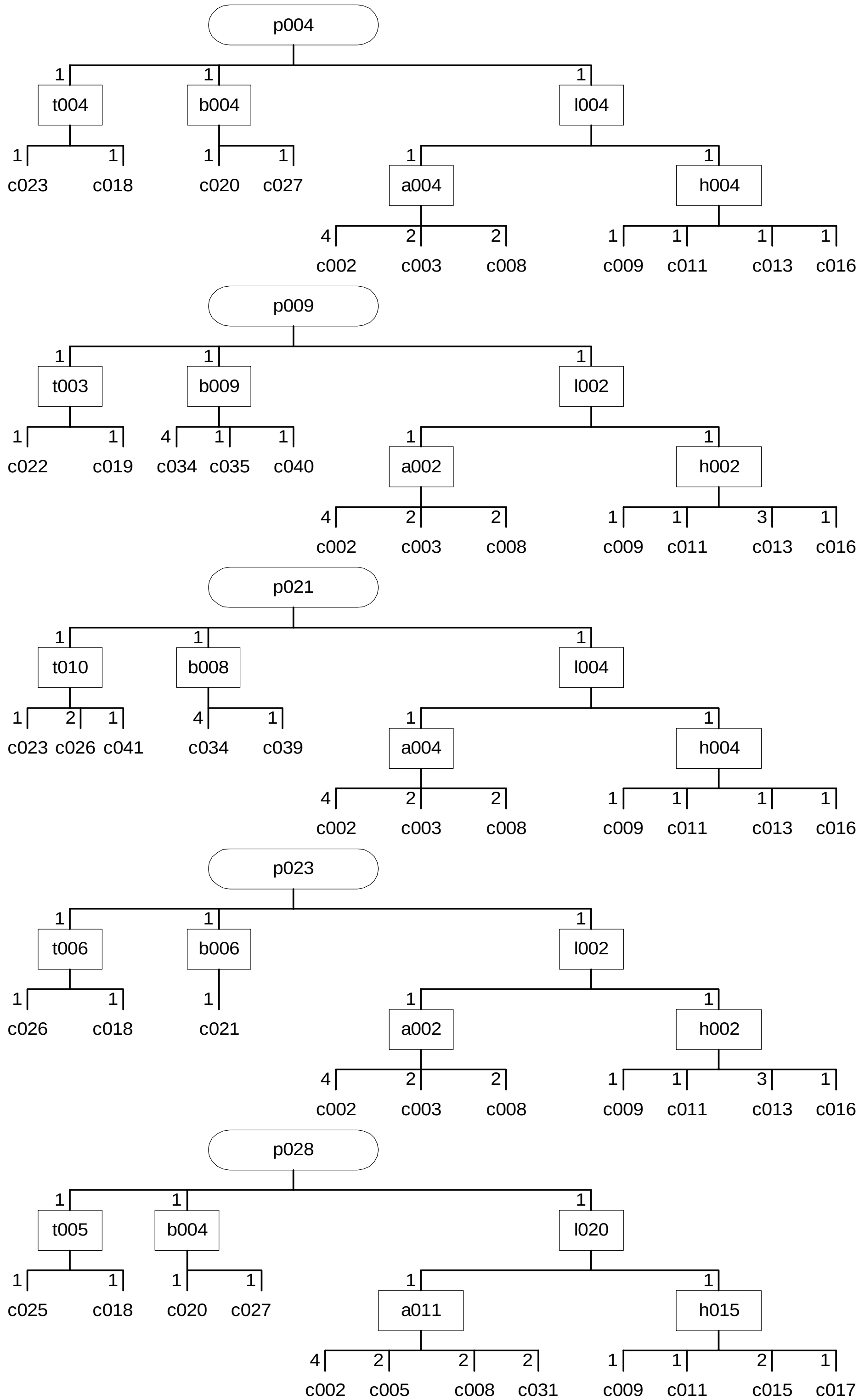


Figure 4.19. Similar products for Conceptual Design 1 at similarity level 0.5

4.5.2. Case 2: A conceptual design with new information

For non-existing components in a database, suppose that a user plans to develop a new lift product and needs to retrieve similar products from vendors' databases. However, the user has new information introduced to a conceptual design such as a new design component or new design module information. Table 4.6.-4.7. shows the list of retrieved product designs derived by new module and new component components information for the Conceptual Design 2.

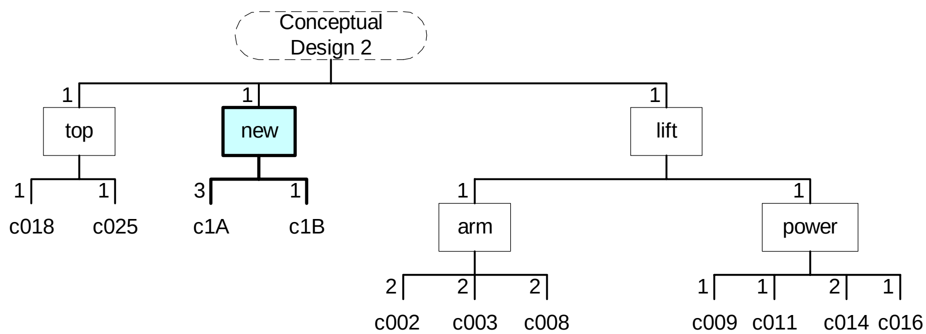


Figure 4.20. Conceptual Design 2's component and structure information

Similarity Level	Retrieved Product No.
0.3	1, 2, 4, 5, 7, 8, 9, 14, 16, 20, 21, 23, 24, 28, 32, 35
0.5	2, 4, 8, 9, 21, 23, 28
0.7	2, 4, 23

Table 4.6. Retrieved product designs for Conceptual Design 2

For similarity level 0.3, 0.5 and 0.7, Product No. 2, No. 4 and No. 23 are retrieved and shown as the following Figure 4.21.

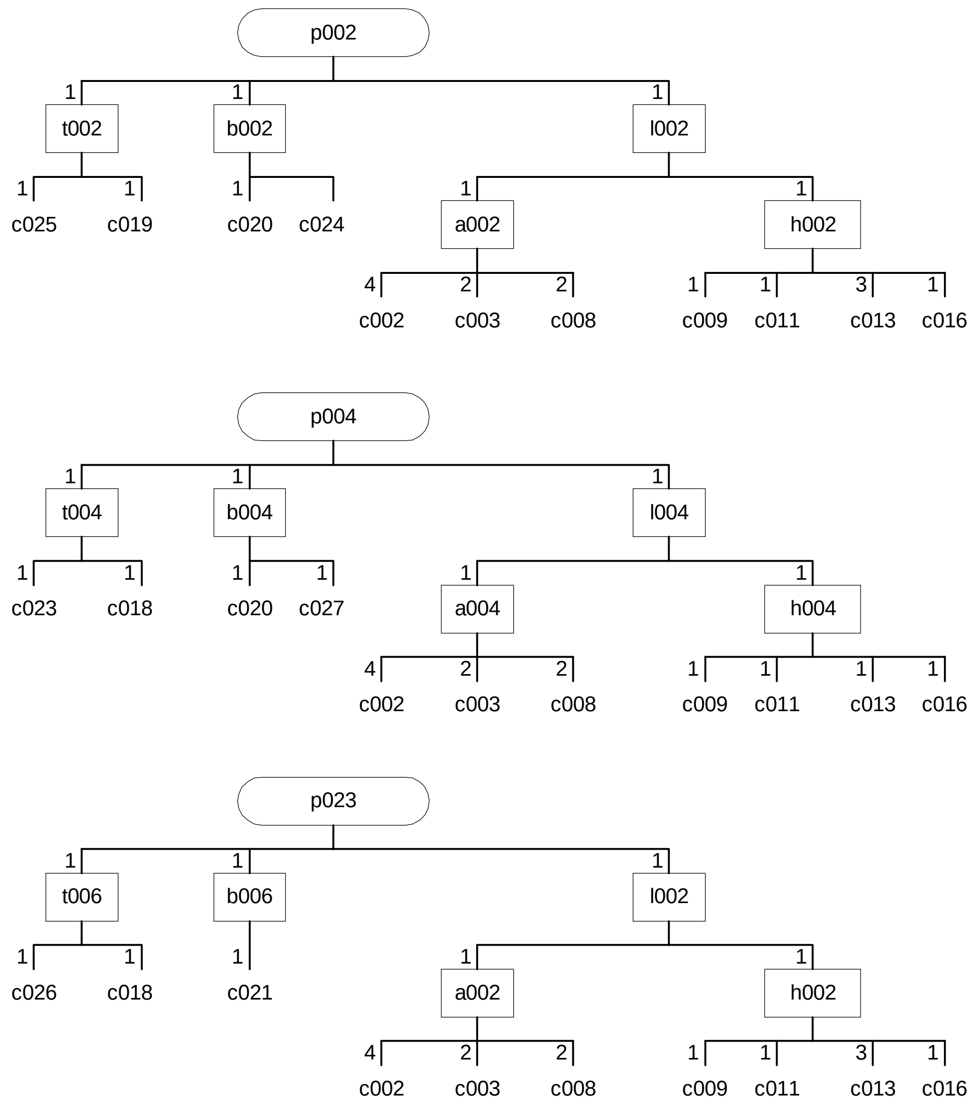


Figure 4.21. Similar products for Conceptual Design 2

For another example, the Conceptual Design 3 is used as a query input. The Conceptual Design 3 contains two new modules and existing components from other top module and arm module as shown in Figure 4.22.

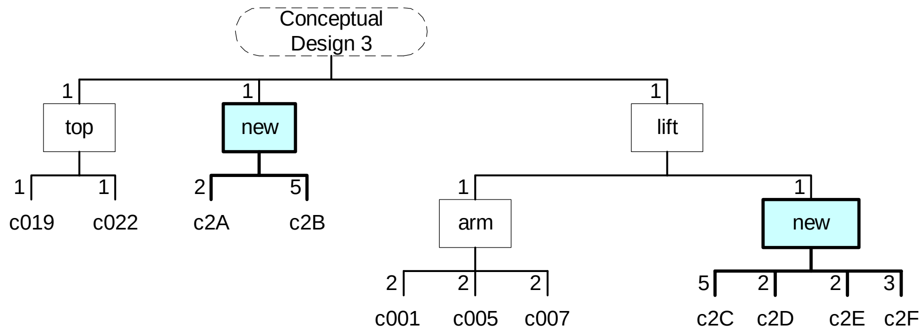


Figure 4.22. Conceptual Design 3's component and structure information

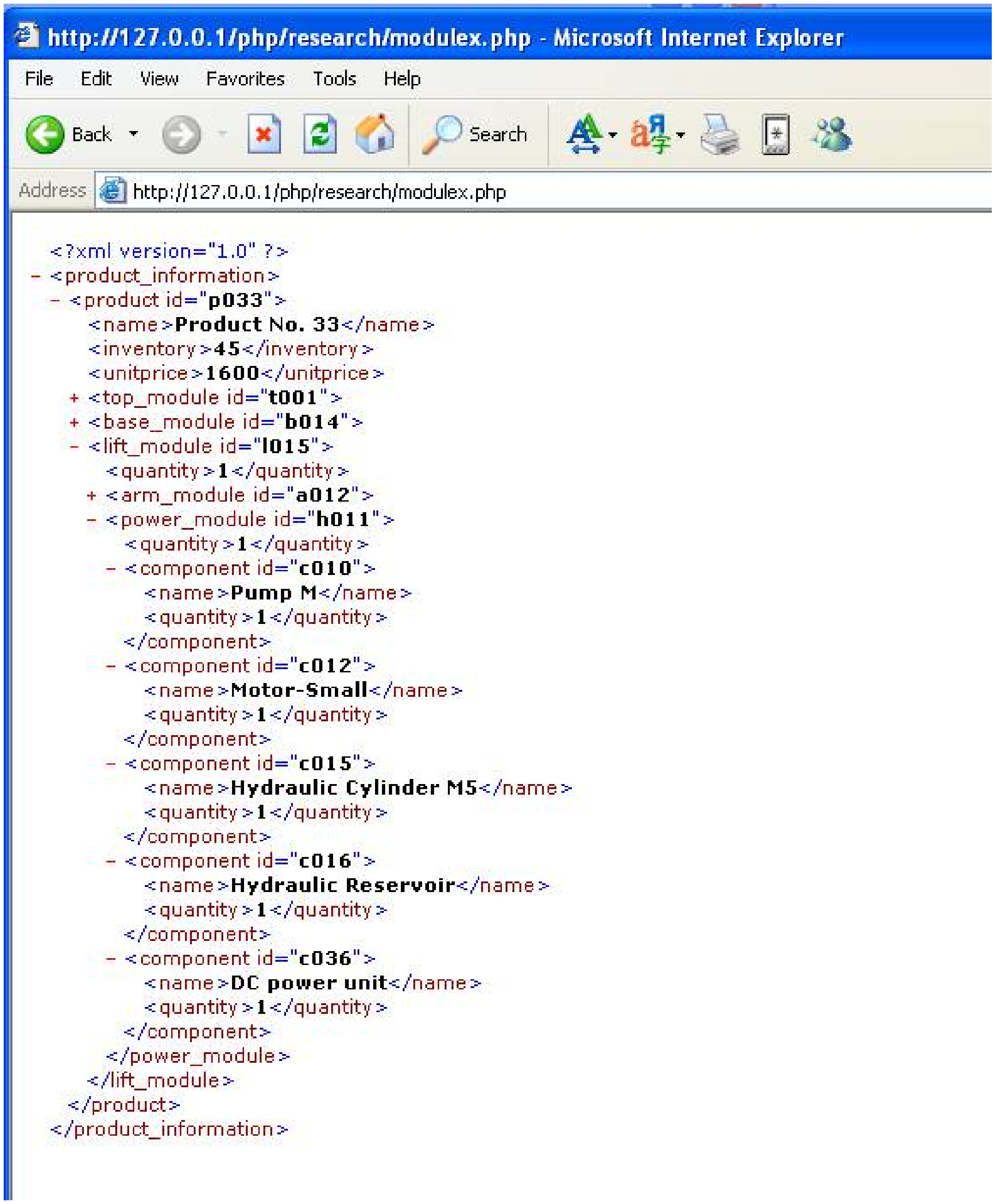
Similarity Level	Retrieved Product No.
0.3	1, 2, 4, 5, 7, 8, 9, 14, 16, 20, 21, 23, 24, 28, 32, 35
0.5	3, 6, 12, 13, 15, 26, 27
0.7	3, 10, 22

Table 4.7. Retrieved product designs for the Conceptual Design 3

For a full result review of the Conceptual Design 3, the product structure of each product is shown in Appendix D. The result shows that reference products have partial similarity to the Conceptual Design 3. Implementing the proposed method, the retrieval system not only has the flexibility of changing the similarity level of retrieved reference products, but also the capability of dealing with new information that a database has not yet contained. This example demonstrates that even if new information is introduced, the proposed method still can retrieve similar products based on partial matching.

4.6. XML utilization with proposed Web-based system

This section briefly describes the benefit of having utilized eXtensible Markup Language (XML) as an alternative for the retrieval system. The XML technology is derived from Standard Generalized Markup Language (SGML, ISO 8879) a tool well-known for its simple, flexible, extensible, and neutral capabilities (http://www.w3c.org/XML). In addition, XML is a file format designed to bring structured information to the Web. It allows users to define their own set of markup tags related to their documents. The XML conversion method for supporting product structure development give database users content- and structure-based information about the products the databases contain. By adding one more dimension of the product component structure level to the conventional database, we have been able to use our proposed component and structural information to obtain a structure-based product relation model. We can then transform our modular product database to XML format. To provide a clear understanding, Product No. 33 is used as an example of XML representation in the following two figures.




```
<?xml version="1.0" ?>
- <product_information>
  - <product id="p033">
      <name>Product No. 33</name>
      <inventory>45</inventory>
      <unitprice>1600</unitprice>
    + <top_module id="t001">
    + <base_module id="b014">
    - <lift_module id="l015">
        <quantity>1</quantity>
      + <arm_module id="a012">
      - <power_module id="h011">
          <quantity>1</quantity>
        - <component id="c010">
            <name>Pump M</name>
            <quantity>1</quantity>
          </component>
        - <component id="c012">
            <name>Motor-Small</name>
            <quantity>1</quantity>
          </component>
        - <component id="c015">
            <name>Hydraulic Cylinder M5</name>
            <quantity>1</quantity>
          </component>
        - <component id="c016">
            <name>Hydraulic Reservoir</name>
            <quantity>1</quantity>
          </component>
        - <component id="c036">
            <name>DC power unit</name>
            <quantity>1</quantity>
          </component>
        </power_module>
      </lift_module>
    </product>
  </product_information>
```

Figure 4.23. An example of XML presentation

The following is an example of XML document of structure and component for Product No. 33.

```
<?xml version="1.0"?>
<product_information>
      <product id='p033'>
            <name>Product No. 33</name>
            <inventory>45</inventory>
            <unitprice>1600</unitprice>
            <top_module id='t001'>
                  <quantity>1</quantity>
                  <component id='c018'>
                        <name>Platform TS</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c025'>
                        <name>Ball transfer top</name>
                        <quantity>1</quantity>
                  </component>
            </top_module>
            <base_module id='b014'>
                  <quantity>1</quantity>
                  <component id='c024'>
                        <name>Fork Pocket</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c034'>
                        <name>Flange Wheel</name>
                        <quantity>4</quantity>
                  </component>
                  <component id='c035'>
                        <name>Push Bar</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c039'>
                        <name>Platform BW</name>
                        <quantity>1</quantity>
                  </component>
            </base_module>
            <lift_module id='l015'>
                  <quantity>1</quantity>
                  <arm_module id='a012'>
                        <quantity>1</quantity>
                        <component id='c002'>
                              <name>Stabilizer Type B</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c004'>
                              <name>Upper Lift Arm F</name>
                              <quantity>3</quantity>
                        </component>
                        <component id='c007'>
                              <name>Lower Lift Arm Type T</name>
                              <quantity>3</quantity>
                        </component>
                        <component id='c030'>
                              <name>Lift Arm Axle T</name>
```

```
                        <quantity>3</quantity>
                  </component>
                  <component id='c037'>
                        <name>Stabilizer Type K</name>
                        <quantity>2</quantity>
                  </component>
            </arm_module>
            <power_module id='h011'>
                  <quantity>1</quantity>
                  <component id='c010'>
                        <name>Pump M</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c012'>
                        <name>Motor-Small</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c015'>
                        <name>Hydraulic Cylinder M5</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c016'>
                        <name>Hydraulic Reservoir</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c036'>
                        <name>DC power unit</name>
                        <quantity>1</quantity>
                  </component>
            </power_module>
      </lift_module>
   </product>
</product_information>
```


Figure 4.24. An example of XML document of Product No. 33

With XML, data can be exchanged between incompatible systems. One of the most time-consuming challenges for developers has been to exchange data between such systems over the Internet. Converting the data to XML can greatly reduce this complexity and can create data that can be read by many different types of applications.

4.7. Summary of this chapter

In conclusion, a Web-based platform for a modular product-design retrieval system has been proposed and has been presented in this research. Each design in the developed system is indexed by a unified indexing scheme consisting of the structure and component information of a design. To obtain reference designs after utilizing the unified indexing model, a Fuzzy-ART neural network was implemented in order to handle retrieval algorithms. The proposed model enables us to use the retrieval system for e-commerce in a Web-based environment. It also puts forth an indexing mechanism that can be used for a variety of product databases. This platform will give the user the ability to retrieve product information at the front-office level of a virtual enterprise from each member-company database in order to generate production delivery plans and cost estimation. Without this Web-based platform, these tasks may be very difficult because communication between users and designers is generally time-consuming. Moreover, without the proposed platform, product development may be delayed by the lack of instant information exchange, as well as the lack of instant information availability. Vendors, suppliers, manufacturers, and customers may be located in different places, as well as in different time zones. As one can see from efforts in these Web-based applications, Web technology is accepted as a highly useful information infrastructure for providing much-needed collaboration among organizations.

Thus, users are able now to rapidly retrieve their reference product via a Web-based modular product retrieval system. Instant communication between vendors, suppliers, manufacturers, and customers has become a very significant need in order to assess and shorten the time for product development. This, in turn, will expedite the delivery of products to the market. Thus, implementing the proposed method will expedite product development, as well as enable companies to retrieve reference designs based on modular or structural similarity.

CHAPTER 5

CONCLUSION AND DISCUSSION

5.1. Summary of the dissertation

The manufacturing industry has modified and shifted its approach from traditional manufacturing to agile manufacturing. New economies and markets recently changed their business practices, resulting in a new generation of empowered customers who can buy from markets scattered across the globe. Moreover, companies need to develop new methods and techniques to react rapidly to required changes in products and market trends and to shorten the product-development cycle. With the increasing worldwide market and the gradually more-competitive manufacturing environment, new product designs need to be developed with shorter lead-times and better overall performance. Stimulating new product design development, while also responding to customer needs, is a key to a successful marketing strategy. Embracing the approach of shared databases and information exchanges enables the entire enterprise to expedite orders and to ensure prompt delivery of goods.

In order to develop new products that reflect the customization movement, the modularity approach needs to be implemented. More specifically, modular products are one of the essential aspects of agile manufacturing, which ensures variability in products that fulfill potentially diverse customer requirements. The production of customized products will increase in response to the individual demands of customers. Today's products possess higher complexities, in that they have systematic structures in physical function, manufacturing units, and so on. Researchers have developed different approaches to designing structural products. The most popular and most commonly used approach in contending with structural products is the modularity approach. More specifically, modular products are one of the essential aspects of agile manufacturing, which ensures variability in products that fulfill the potentially diverse customer requirements. The need to increase overall performance in the design process makes retrieval of reference designs attractive to many researchers. There are several studies that address modularity with respect to structural representations. However, these studies do not address full-function data management systems, which still are needed. The problem is that there is not yet a unified method for supporting product structure development and for integrating information. There is a lack of support in the planning and modification of a product configuration. This concerns initial design, as well as the reuse of modules and of product structures when creating new products.

Another aspect that current research has not yet adequately addressed is product data retrieval. In addition, those that did contend with product data retrieval addressed one-level retrieval models, but ignored multilevel products or structural products. Thus, limitations persist in current intelligent retrieval systems. To answer the aforementioned difficulty, a unified indexing method was introduced for this study. This proposed indexing method would include information about product structure and components.

This research proposed a method of indexing product structures that must assist the designer in responding to the different needs of the customer, as well as assist with retrieving similar products. Furthermore, the developed system should not only implement a multidimensional indexing database scheme to facilitate searching for structural product data, but also have the ability to achieve an Internet-based interface retrieval system environment, which would address the problem of product delays due to a lack of instant information exchange.

However, the problem remains that there is not yet a method for supporting product structure development and for integrating information. Many design database systems currently ignore content- and structure-based analysis of the products they contain. A product/component database is the most common type used in a database management system. These systems index only models based on simple properties that have little or nothing to do with the structure of the part, such as the part's name or the designer's name. By adding one more dimension of the product component structure level to the conventional database, we have been able to use our proposed component and structural information to obtain a structure-based product relation model.

A prototype of the modular product design retrieval system has been proposed and has been implemented in this research. Each design in the developed system is indexed by a unified index scheme consisting of the structure and component information of a design. To obtain reference designs after utilizing the unified indexing model, a

Fuzzy-ART neural network has been implemented in order to handle retrieval algorithms. Furthermore, the proposed model also enables us

- to use the retrieval system for e-commerce in Web-based environment;
- to study the adaptability of proposed indexing mechanism for a variety of product databases; and
- to give a user the ability to retrieve product information in the front-office operation of a virtual enterprise from each member-company database to generate production delivery plans and cost estimation.

As a result of the proposed method, there will be an intelligent retrieval system for product data management systems that gives an enterprise the ability to communicate with its partners efficiently. Enterprise members will be able to interact with each other's databases and will be able to retrieve information to generate a production plan without any obstacles. A framework of our study is shown in Figure 5.1.

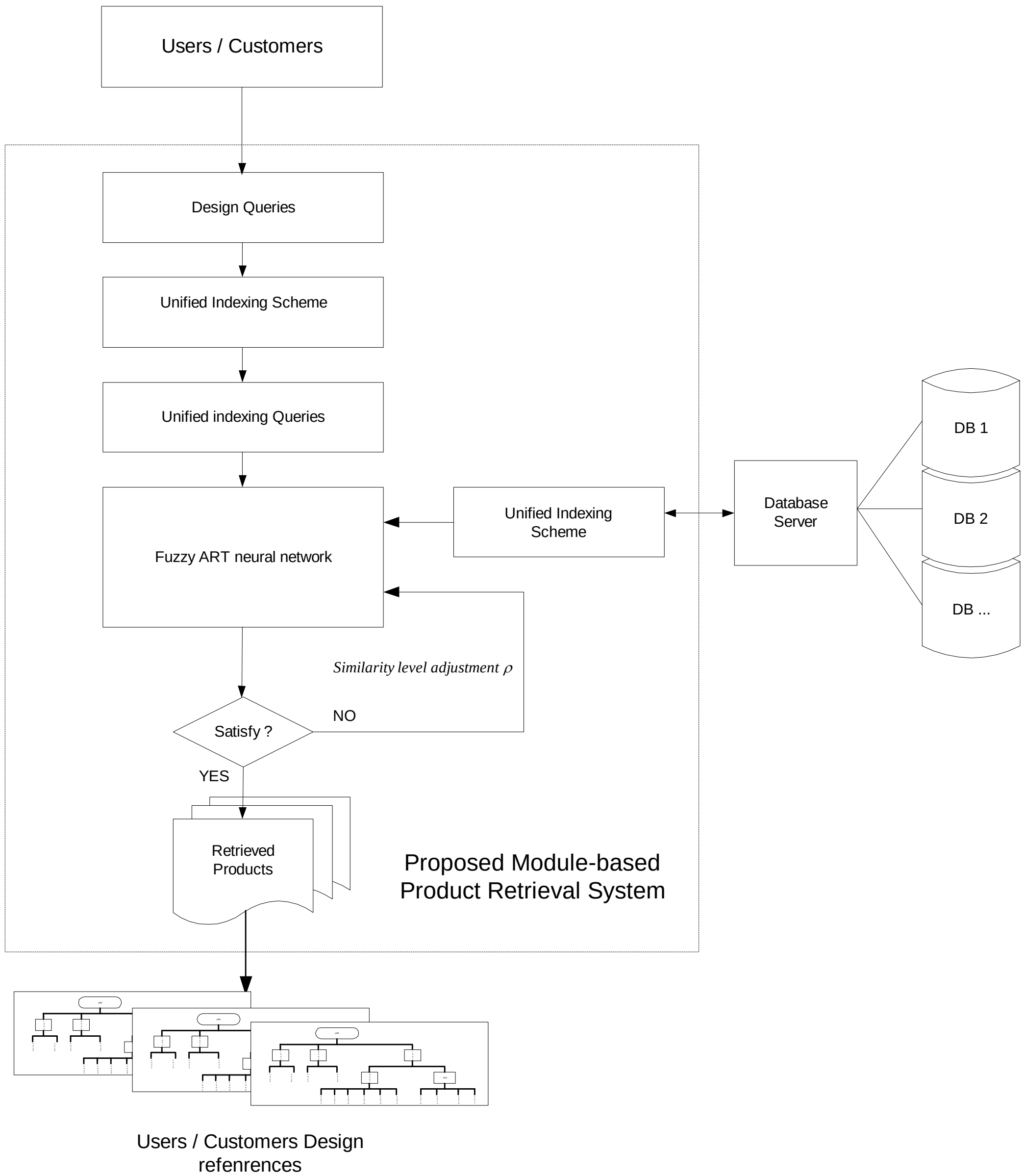


Figure 5.1. The framework of the proposed design retrieval system

5.2. Comparison and discussion

Comparison is discussed to show the performance of the proposed study. According to Figure 5.2, compared with Group Technology (GT), and feature-based indexing methods, the *S* matrix is an appropriate solution method to distinguish dissimilarity (viz., the aforementioned obstacle that GT and feature-based methods do not recognize differences).

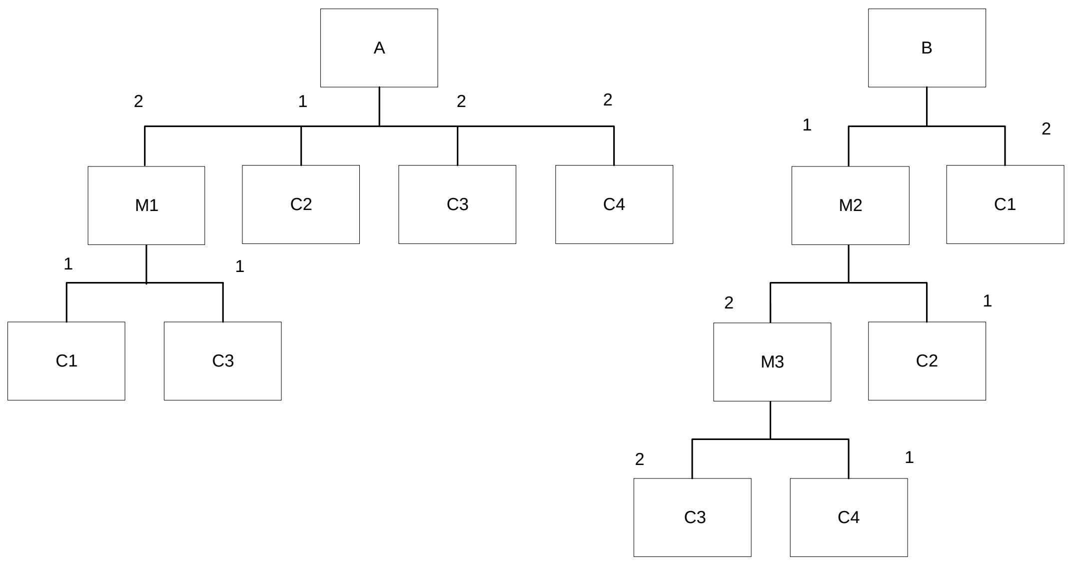


Figure 5.2. Examples of alternative product structure

	C1	C2	C3	C4
A	2	1	4	2
B	2	1	4	2

Table 5.1. Product A and Product B components

$$S_A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}; \qquad S_B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 4 & 0 & 0 & 0 & 0 & 0 & 4 & 2 \\ 2 & 0 & 0 & 0 & 0 & 0 & 2 & 1 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \end{bmatrix}$$

As we can see from the *S* matrix, the products are different from each other. S_A and S_B are separated and clustered in different groups when similarity parameter $\rho > 0.3$. As a result, the *S* matrix is an appropriate method to distinguish the dissimilarities that traditional retrieval method do not recognize.

Even though a GT indexing scheme works efficiently with the manufacturing process, its use as a design retrieval system still has several problems. The problems include defining main features of designs, a suitable GT coding selection, and part designs encoding. Feature-based indexing is inflexible from the user's view because users need to follow queries to do retrieval tasks systematically. Moreover, most industrial products are assembled parts, the need to develop a method to retrieve assembled parts, or composed components still remains. The Boolean-based information retrieval system retrieves all the relevant information that matches the query exactly. Thus, the Boolean-based information retrieval system discards all non-matches or partial matches and only includes exact matches in the query.

In this study, the information can be put into numerical form as the proposed unified indexing scheme, which is represented by a component and structure matrix, S. It shows how many of each assembly or module is required directly by any other module and its structure. The component and structure matrix, S, is the way to achieve an application of modular design retrieval because (1) it is a unique presentation of a structural product and provides a uniform representation; and (2) it lists all modules, as well as all components, in one representation.

As previously mentioned, the user cannot provide a query that is perfectly relevant to target products. This retrieval system is effective enough to retrieve possible similar products based on *"weak"* similarity of component and structure. In addition, the proposed Fuzzy-ART retrieval system give us the ability to retrieve a group of similar products at a lower similarity level, while other retrieval systems may only tell us the value of dissimilarity because Fuzzy-ART neural network can tolerate a certain degree of incomplete query. Thus, a similarity algorithm based on the unified indexing scheme is the most appropriate method to use. In conclusion, comparisons between previous researches and our proposed approach can be summarized as following table:

Approach	Structural similarity search	Component information	Different module definition	Remarks
Group Technology	No	Yes	No	-Utility is limited if data are not standardized. -Incomplete query is not allowed in GT based methods. -Require significant human labeling
Feature-based	No	Yes	No	-Structural information is not included. -Not appropriate for assembled products. -Flat level database. -Pre-defined feature set. -Geometric similarity only.
Graph-based	Yes	No	Yes	-No component information -Fixed matching.
Image/Shape-based	No	No	No	-Multimedia database, not for manufacturing products. -Disappearance of hidden components and internal features are unavoidable.
Propose Method	Yes	Yes	Yes	-Linear retrieving time with respect to database size

				-Structural and component information in one representation. -Ability to handle different module definitions. -Neglect a new component presented in a query and handles a case as an incomplete information query. -*"weak"* similarity retrieval

Table 5.2. Comparisons between previous researches and propose method

5.3. Major contributions

Within the framework of the unified indexing scheme and module-based product retrieval system, this study has addressed the problems found in recent product retrieval system researches. Conclusively, the contributions of this research can be summarized as:

- the ability to handle a product module's definition from different users' own views and to assist the designer in responding to needs of the customer, as well as to assist with retrieving similar products based on different user definitions of modules;
- the ability to retrieve products based on structural and component similarity, and the ability to search an incomplete query of a structural product or system as well as *"weak"* similarity of products.

- the ability to integrate the proposed study into an existing database management system through Web-based technology, which would facilitate an e-commerce environment.

5.4. Further research

Because this study incorporates structure-based products and utilization of XML-based data, the system allows data to be exchanged between incompatible systems. Converting the data to XML can reduce this complexity greatly and can create data that can be read by many different types of applications because XML is well known for its simple, flexible, extensible, and neutral capabilities.

Further research in this area should include investigation of mapping XML to the Standard for the Exchange of Product Model Data (STEP), because the neutral features of both XML and STEP make them independent of any application platform. Investigating the International Standard Organization (ISO) STEP provides us with the ability to develop problem-free products or production plans from incompatibility issues, as long as the ISO standard is still in use.

This study has presented the integration of the unified indexing method for module-based product database with Web-based technology. However, the actual performance of Web-based applications is not yet known. Therefore, further research on Web-based performance should be considered also.

APPENDIX A

FUZZY-ART NEURAL NETWORK

ALGORITHM SUMMARY

The structure of the Fuzzy-ART is shown in figure i. A Fuzzy-ART network performs unsupervised clustering on analogue and binary input patterns.

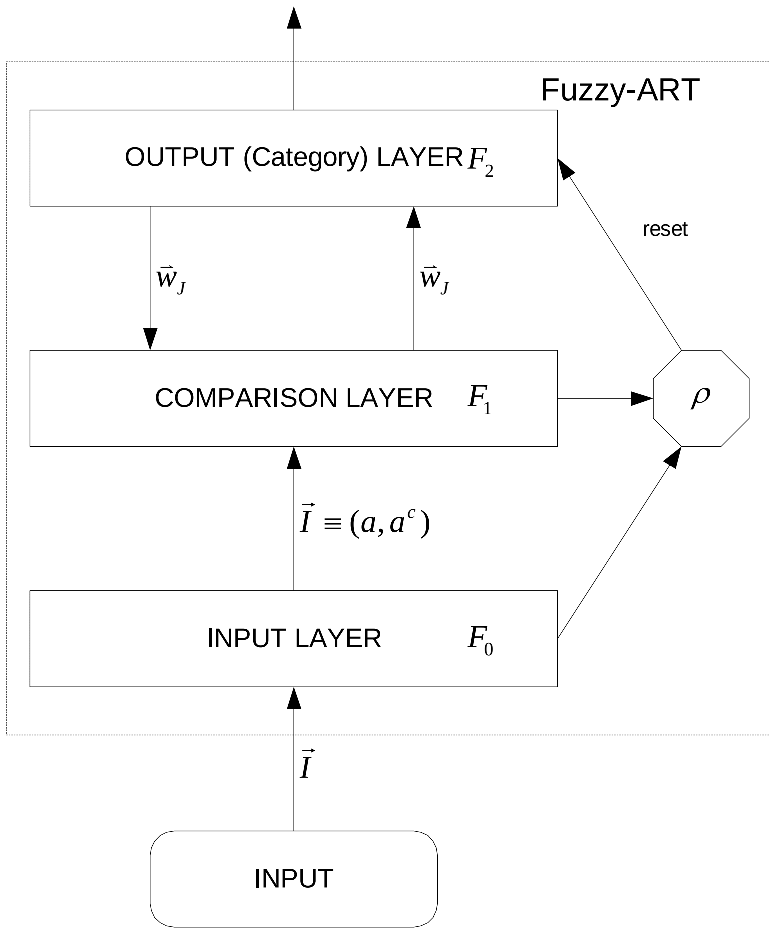


Figure i Fuzzy-ART Neural Network Structure

Fuzzy-ART neural network is composed of three layers: the input layer (F_0), comparison layer (F_1), and output layer (F_2) with *M*, *M* and *N* nodes, respectively. The input layer (F_0) complements the input. The comparison layer (F_1) determines whether the input belongs to an existing cluster of the network. The output layer (F_2) outputs the matching results.

An input vector *I* represented as a vector of fuzzy attributes in the interval [0,1] where each input I is an *M*-dimensional vector.

$$\vec{I} \equiv (I_1, \ldots, I_M) \qquad \text{(a.1)}$$

The pattern that defines each category (*j*) is a weight vector

$$\vec{w}_j \equiv (w_{j1}, \ldots, w_{jM}) \qquad \text{(a.2)}$$

Initially,

$$w_{j1} = \ldots = w_{jM} = 1 \qquad \text{(a.3)}$$

Each category is *uncommitted* until a node is selected for coding it becomes *committed.* Each weight w_{ji} is monotone non-increasing through time and converge to a limit.

Fuzzy-ART dynamics are determined by three parameters: a choice parameter α and a learning parameter β and vigilance parameter ρ where $\alpha > 0$, $\beta \in [0,1]$ and $\rho \in [0,1]$ respectively.

The Fuzzy-ART attempts to classify each input into one of its existing categories based on its similarity to the stored prototype of each category node. For input *I* and each category node *j*, the choice function $T_j(\vec{I})$ is

$$T_j(\vec{I}) = \frac{\left|\vec{I} \wedge \vec{w}_j\right|}{\alpha + \left|\vec{w}_j\right|} \qquad \text{(a.4)}$$

where the choice parameter $\alpha > 0$. The fuzzy intersection (Zadeh 1965) operator $\wedge$ is defined by

$$(\mathbf{x} \wedge \mathbf{y})_i \equiv \min(x_i, y_i) \tag{a.5}$$

and the norm $|\cdot|$ is defined by

$$|\, x \,| \equiv \sum_{i=1}^{M} x_i \tag{a.6}$$

for any *M*-dimension of vector *x*. An input is classified into the j^{th} category and the j^{th} in the output layer is activated if it received the largest input. The network then makes a category choice by select node *j* where

$$T_J = \max\{T_j : j = 1, 2, \ldots, N\} \tag{a.7}$$

If there is more than one index *j* given a maximal T_j, the node with the smallest index is chosen. Thus, nodes are committed in order *j* = 1, 2, 3, ….

By definition resonance is said to occur if the match function of the chosen node meets the following vigilance criterion.

$$\frac{\left|\vec{I} \wedge \vec{w}_J\right|}{\left|\vec{I}\right|} \geq \rho \tag{a.8}$$

where $\rho \in [0,1]$ is the vigilance parameter. Otherwise, the *Mismatch reset* occurs. The j^{th} neuron is deactivated and T_j is reset to -1 for the duration of the input presentation in order to select another output neuron for applying the vigilance criterion through equation (a.4) – (a.8) until it satisfies.

If the input pattern belongs to the j^{th} cluster, the corresponding weight vector is updated according to the equation

$$\vec{w}_J^{(new)} = \beta \, (\, \vec{I} \wedge \vec{w}_J^{(old)} \,) + (\, 1 - \beta \,) \, \vec{w}_J^{(old)}) \qquad \text{(a.9)}$$

where $\beta \in [0,1]$ is the learning rate.

For a fast commitment option, the fast learning rate is suggested to set $\beta = 1$ when J is an uncommitted node, and then to take $\beta < 1$ after the category is committed. Then, to set $\vec{w}_J^{(new)} = \vec{I}$ for the first time category J becomes active.

The proliferation problem can occur in some analog ART system. The problem happens when a large number of inputs erode the norm of weight vectors. To avoid this problem, a complement coding input normalization rule is used. If the input is an *M*-dimensional vector *I*, then the input *I* become the *2M*-dimensional vector for the recognition system.

$$\vec{I} \equiv (\mathbf{a}, \mathbf{a}^c) \equiv (\, a_1, \ldots, a_M \, , a_1^c, \ldots, a_M^c \,) \qquad \text{(a.10)}$$

where $a_1^c \equiv 1 - a_i$.

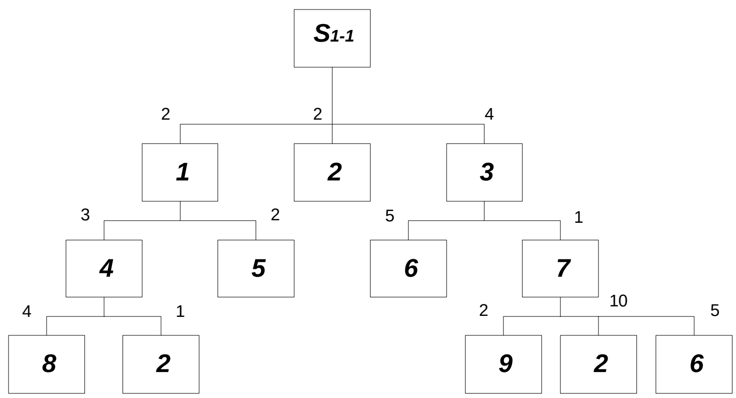
Then, the value of the choice function T_k is reset to 0 for the duration of input presentation to prevent its persistent selection during the search.

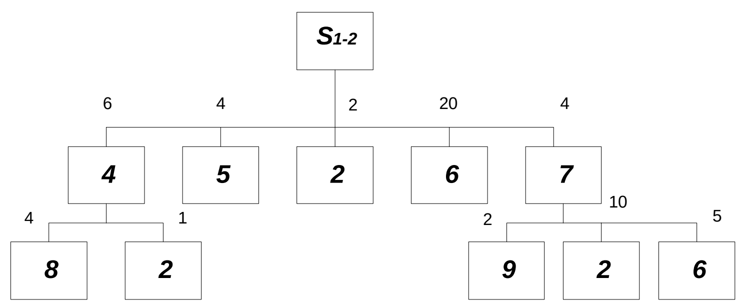
APPENDIX B

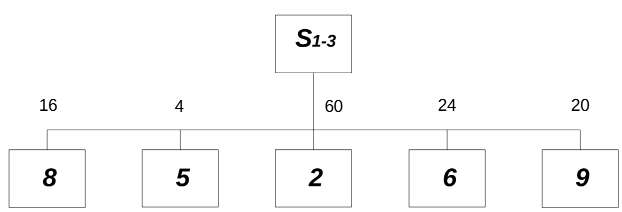
STRUCTURAL PRODUCTS MATRICES

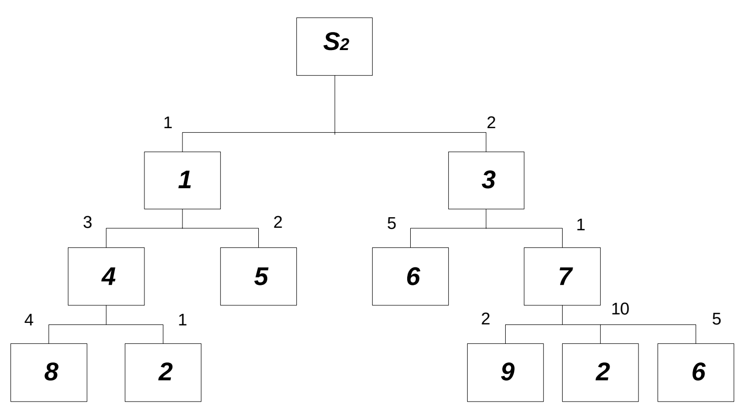
AND RETRIEVING RESULTS

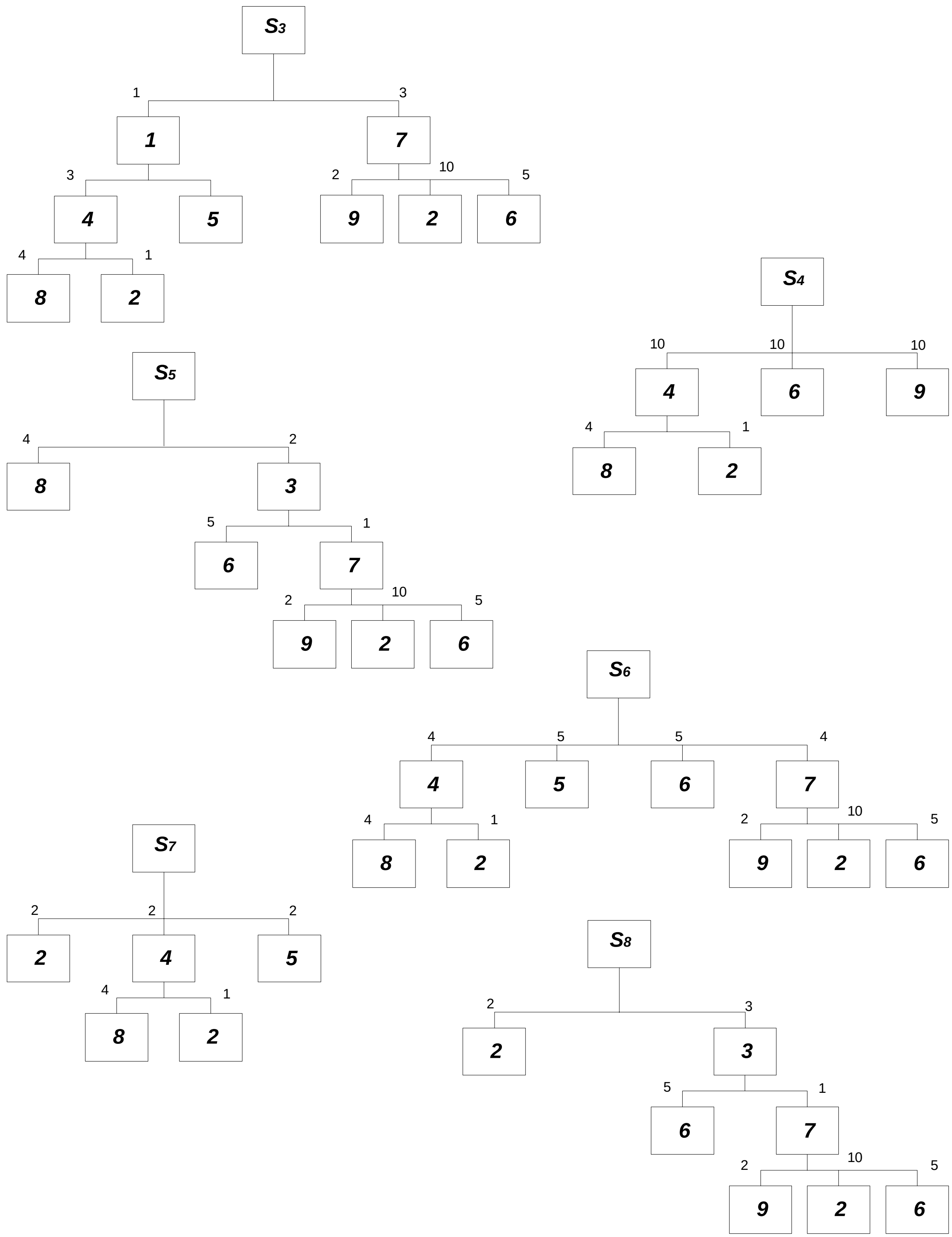
Product Structure Samples










S3
1 3
1 7
3 2 10 5
4 5 9 2 6
4 1
8 2
S4
10 10 10
4 6 9
4 1
8 2
S5
4 2
8 3
5 1
6 7
2 10 5
9 2 6
S6
4 5 5 4
4 5 6 7
4 1 2 10 5
8 2 9 2 6
S7
2 2 2
2 4 5
4 1
8 2
S8
2 3
2 3
5 1
6 7
2 10 5
9 2 6

S Matrix for multiple modular structure views of each modular product

$S_{1\text{-}1}$

0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
16	3	0	2	1	0	0	2	0	0
4	0	0	0	0	0	0	0	0	0
6	3	0	0	0	0	0	0	0	0
4	2	0	0	0	0	0	0	0	0
60	0	0	15	0	0	0	10	0	0
4	0	0	1	0	0	0	0	0	0
24	12	0	0	4	0	0	0	0	0
20	0	0	5	0	0	0	5	0	0

$S_{1\text{-}2}$

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
16	0	0	0	1	0	0	2	0	0
0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	10	0	0
4	0	0	0	0	0	0	0	0	0
24	0	0	0	4	0	0	0	0	0
20	0	0	0	0	0	0	5	0	0

$S_{1\text{-}3}$

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0

S_2

0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0
23	3	0	10	1	0	0	10	0	0
2	0	0	0	0	0	0	0	0	0
3	3	0	0	0	0	0	0	0	0
2	2	0	0	0	0	0	0	0	0
20	0	0	10	0	0	0	5	0	0
2	0	0	1	0	0	0	0	0	0
12	12	0	0	4	0	0	0	0	0
4	0	0	2	0	0	0	2	0	0

S_3

0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0
33	3	0	0	1	0	0	10	0	0

0	0	0	0	0	0	0	0	0	0
3	3	0	0	0	0	0	0	0	0
2	2	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	5	0	0
3	0	0	0	0	0	0	0	0	0
12	12	0	0	4	0	0	0	0	0
6	0	0	0	0	0	0	2	0	0

S_4

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
40	0	0	0	4	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0

S_5

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
20	0	0	10	0	0	0	10	0	0
2	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
20	0	0	10	0	0	0	5	0	0
2	0	0	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
4	0	0	2	0	0	0	2	0	0

S_6

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
44	0	0	0	1	0	0	10	0	0
0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	5	0	0
4	0	0	0	0	0	0	0	0	0
16	0	0	0	4	0	0	0	0	0
8	0	0	0	0	0	0	2	0	0

S_7

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
8	0	0	0	4	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

S_8

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
32	0	0	10	0	0	0	10	0	0
3	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
30	0	0	10	0	0	0	5	0	0
3	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
6	0	0	2	0	0	0	2	0	0

Result from different vigilance parameters for S_1 , S_2 and S_3.

Vigilance Parameter	S				
0.10	# 1:	S1-1	S1-2	S1-3	S2-1
		S2-2	S2-3	S3-1	S3-2
		S3-3			
0.20	# 1:	S1-1	S1-2	S1-3	S2-1
		S2-2	S2-3	S3-1	S3-2
		S3-3			
0.30	# 1:	S1-1	S1-2	S1-3	S2-1
		S2-2	S2-3	S3-1	S3-2
		S3-3			
0.40	# 1:	S1-1	S1-2	S1-3	S2-1
		S2-2	S2-3	S3-1	S3-2
		S3-3			
0.50	# 1:	S1-1	S1-2	S1-3	S2-1
		S2-2	S2-3	S3-1	S3-2
		S3-3			
0.60	# 1:	S1-1	S1-2	S1-3	S2-2
		S2-3	S3-2	S3-3	
	# 2:	S2-1	S3-1		
	# 1:	S1-1	S1-2	S1-3	S2-2
0.70		S2-3	S3-2	S3-3	
	# 2:	S2-1			
	# 3:	S3-1			
0.80	# 1:	S1-1	S1-2	S1-3	S2-3
		S3-3			
	# 2:	S2-1	S2-2	S3-2	
	# 3:	S3-1			
0.90	# 1:	S1-1	S1-2	S1-3	S2-3
	# 2:	S2-1	S2-2		
	# 3:	S3-1	S3-2	S3-3	
0.99	# 1:	S1-1	S1-2	S1-3	
	# 2:	S2-1	S2-2	S2-3	
	# 3:	S3-1	S3-2	S3-3	

Result from different vigilance parameters for S_1 to S_8.

Vigilance Parameter	S				
0.10	#1:	S1-1	S1-2	S1-3	S2
		S3	S4	S5	S6
		S7	S8		
0.20	#1:	S1-1	S1-2	S1-3	S2
		S3	S4	S5	S6
		S7	S8		
0.30	#1:	S1-1	S1-2	S1-3	S2
		S3	S4	S5	S6
		S7	S8		
0.40	#1:	S1-1	S1-2	S1-3	S2
		S3	S4	S5	S6
		S7	S8		
0.50	#1:	S1-1	S1-2	S1-3	S4
		S5	S6	S7	S8
	#2:	S2	S3		
0.60	#1:	S1-1	S1-2	S1-3	S4
		S5	S7		
	#2:	S2	S3	S6	S8
0.70	#1:	S1-1	S1-2	S1-3	S4
		S7			
	#2:	S2	S3	S5	S6
		S8			
0.80	#1:	S1-1	S1-2	S1-3	
	#2:	S2	S3	S4	S7
	#3:	S5	S8		
	#4:	S6			
0.90	#1:	S1-1	S1-2	S1-3	
	#2:	S2	S3		
	#3:	S4	S7		
	#4:	S5	S8		
	#5:	S6			
0.99	#1:	S1-1	S1-2	S1-3	
	#2:	S2	S5		
	#3:	S3			
	#4:	S4			
	#5:	S6	S7		
	#6:	S8			

APPENDIX C

LIST OF PRODUCT DATABASE TABLES

List of database table description (SQL Language)

```
CREATE TABLE tproduct
(
	pid	varchar(20),
	pname varchar(50),
	pstock	int,
	pprice	float,
	PRIMARY KEY (pid)
);

CREATE TABLE tprotop
(
	pid	varchar(20),
	tid	varchar(20),
	tq	int,
	PRIMARY KEY (pid,tid),
	FOREIGN KEY (tid) REFERENCES ttopcom
);

CREATE TABLE tprobase
(
	pid	varchar(20),
	bid	varchar(20),
	bq	int,
	PRIMARY KEY (pid,bid),
	FOREIGN KEY (bid) REFERENCES tbasecom
);

CREATE TABLE tprolift
(
	pid	varchar(20),
	lid	varchar(20),
	lq	int,
	PRIMARY KEY (pid,lid),
	FOREIGN KEY (lid) REFERENCES tliftcom
);

CREATE TABLE tprocom
(
	pid	varchar(20),
	cid	varchar(20),
	cq	int,
	PRIMARY KEY (pid,cid),
	FOREIGN KEY (cid) REFERENCES tcomponent
);

CREATE TABLE ttopcom
(
	tid	varchar(20),
	cid	varchar(20),
	cq	int,
	PRIMARY KEY (tid,cid),
```

```
    FOREIGN KEY (cid) REFERENCES tcomponent
);

CREATE TABLE tbasecom
(
    bid   varchar(20),
    cid   varchar(20),
    cq    int,
    PRIMARY KEY (bid,cid),
    FOREIGN KEY (cid) REFERENCES tcomponent
);

CREATE TABLE tliftcom
(
    lid   varchar(20),
    cid   varchar(20),
    cq    int,
    PRIMARY KEY (lid,cid),
    FOREIGN KEY (cid) REFERENCES tcomponent
);

CREATE TABLE tarmcom
(
    aid   varchar(20),
    cid   varchar(20),
    cq    int,
    PRIMARY KEY (aid,cid),
    FOREIGN KEY (cid) REFERENCES tcomponent
);

CREATE TABLE tpowcom
(
    hid   varchar(20),
    cid   varchar(20),
    cq    int,
    PRIMARY KEY (hid,cid),
    FOREIGN KEY (cid) REFERENCES tcomponent
);

CREATE TABLE tliftarm
(
    lid   varchar(20),
    aid   varchar(20),
    aq    int,
    PRIMARY KEY (lid,aid),
    FOREIGN KEY (aid) REFERENCES tarmcom
);

CREATE TABLE tliftpow
(
    lid   varchar(20),
    hid   varchar(20),
    hq    int,
    PRIMARY KEY (lid,hid),
```

```
      FOREIGN KEY (hid) REFERENCES tpowcom
);

CREATE TABLE tcomponent
(
      cidx  int,
      cid   varchar(20),
      cname varchar(50),
      cstock      int,
      cprice      float,
      cvendor     varchar(50),
      cmodule varchar(20),
      PRIMARY KEY (cid)
);
```

List of Lift database tables and data

```
Product Table
+------+---------------+--------+--------+
| pid  | pname         | pstock | pprice |
+------+---------------+--------+--------+
| p001 | Product No. 1  |    100 |   2000 |
| p002 | Product No. 2  |    200 |    500 |
| p003 | Product No. 3  |     30 |   1500 |
| p004 | Product No. 4  |     45 |    320 |
| p005 | Product No. 5  |     56 |    450 |
| p006 | Product No. 6  |     65 |   5000 |
| p007 | Product No. 7  |     70 |    300 |
| p008 | Product No. 8  |     84 |   2600 |
| p009 | Product No. 9  |      3 |    300 |
| p010 | Product No. 10 |      4 |    500 |
| p011 | Product No. 11 |     56 |    600 |
| p012 | Product No. 12 |     76 |    700 |
| p013 | Product No. 13 |     14 |    900 |
| p014 | Product No. 14 |    782 |    300 |
| p015 | Product No. 15 |     42 |    345 |
| p016 | Product No. 16 |     45 |    567 |
| p017 | Product No. 17 |     21 |    560 |
| p018 | Product No. 18 |     95 |    890 |
| p019 | Product No. 19 |     56 |    920 |
| p020 | Product No. 20 |     56 |    956 |
| p021 | Product No. 21 |     77 |    892 |
| p022 | Product No. 22 |    200 |    900 |
| p023 | Product No. 23 |     30 |   1200 |
| p024 | Product No. 24 |     45 |   1300 |
| p025 | Product No. 25 |     56 |   4100 |
| p026 | Product No. 26 |     65 |   3100 |
| p027 | Product No. 27 |     70 |   3900 |
| p028 | Product No. 28 |     84 |    480 |
| p029 | Product No. 29 |     92 |    590 |
| p030 | Product No. 30 |      2 |    990 |
| p031 | Product No. 31 |      3 |    930 |
```

p032	Product No. 32	97	400
p033	Product No. 33	45	1600
p034	Product No. 34	155	1000
p035	Product No. 35	12	300
p036	Product No. 36	22	400
p037	Product No. 37	200	930
p038	Product No. 38	30	2150
p039	Product No. 39	45	300
p040	Product No. 40	56	2149
p041	Product No. 41	65	2500
p042	Product No. 42	70	3500

Component Table

cid	cname	cstock	cprice	cvendor
c001	Stabilizer Type A	578	89	AL company
c002	Stabilizer Type B	550	90	AB company
c003	Upper Lift Arm A	466	67	MO company
c004	Upper Lift Arm F	438	89	HK company
c005	Upper Lift Arm W	410	39	HK company
c006	Lower Lift Arm Type I	50	72	HK company
c007	Lower Lift Arm Type T	53	54	FL company
c008	Lower Lift Arm Type M	270	28	HK company
c009	Pump S	298	300	HK company
c010	Pump M	326	400	IN company
c011	Motor-Large	59	1000	IN company
c012	Motor-Small	62	100	IN company
c013	Hydraulic Cylinder M3	71	600	HK company
c014	Hydraulic Cylinder M4	102	53	IN company
c015	Hydraulic Cylinder M5	130	900	HK company
c016	Hydraulic Reservoir	158	20	HK company
c017	Hydraulic Reservoir II	186	60	TH company
c018	Platform TS	214	100	TH company
c019	Platform TM	47	100	TH company
c020	Platform BM	44	109	IN company
c021	Platform BL	41	300	MO company
c022	Turn table	11	40	MO company
c023	Tilting Top	23	90	TX company
c024	Fork Pocket	20	30	TX company
c025	Ball transfer top	123	100	TX company
c026	Antiskid top	14	10	MO company
c027	Toe sensor	11	50	HK company
c028	Outer Lift Arm XL	123	234	TX company
c029	Inner Lift Arm T8	84	44	TX company
c030	Lift Arm Axle T	60	23	TX company
c031	Lift Arm Axle M	90	20	HK company
c032	Stabilizer Leg	900	90	IN company
c033	Hand Rail	20	900	MO company
c034	Flange Wheel	60	20	MO company
c035	Push Bar	100	300	TX company

c036	DC power unit	100	400	TX company
c037	Stabilizer Type K	109	1000	TX company
c038	Outer Lift Arm T8	118	100	TX company
c039	Platform BW	123	300	HK company
c040	Platform BN	84	40	HK company
c041	Platform TG	60	90	TH company

Product and its modules table

pid	tid	bid	lid
p001	t001	b001	l001
p002	t002	b002	l002
p003	t003	b003	l003
p004	t004	b004	l004
p005	t005	b005	l005
p006	t006	b006	l006
p007	t001	b007	l008
p008	t002	b008	l004
p009	t003	b009	l002
p010	t004	b010	l003
p011	t005	b005	l014
p012	t010	b006	l013
p013	t009	b011	l007
p014	t008	b012	l005
p015	t007	b013	l006
p016	t006	b014	l001
p017	t012	b011	l015
p018	t011	b007	l012
p019	t012	b010	l006
p020	t011	b009	l005
p021	t010	b008	l004
p022	t008	b007	l003
p023	t006	b006	l002
p024	t004	b005	l001
p025	t002	b001	l010
p026	t001	b002	l007
p027	t003	b003	l007
p028	t005	b004	l020
p029	t007	b005	l016
p030	t009	b006	l011
p031	t011	b004	l011
p032	t012	b007	l008
p033	t001	b014	l015
p034	t002	b013	l019
p035	t003	b012	l017
p036	t006	b011	l010
p037	t007	b004	l012
p038	t008	b003	l009
p039	t009	b002	l018
p040	t004	b001	l009
p041	t002	b013	l013

p042	t005	b008	l014

Lift Module and its modules table

lid	aid	hid
l001	a001	h001
l002	a002	h002
l003	a003	h003
l004	a004	h004
l005	a005	h005
l006	a006	h006
l007	a007	h012
l008	a007	h001
l009	a001	h011
l010	a009	h006
l011	a009	h008
l012	a012	h009
l013	a007	h013
l014	a010	h010
l015	a012	h011
l016	a008	h013
l017	a011	h014
l018	a013	h005
l019	a014	h009
l020	a011	h015

Arm module and its components table

a001	c002	4
a001	c004	2
a001	c006	2
a002	c002	4
a002	c003	2
a002	c008	2
a003	c001	4
a003	c005	3
a003	c006	3
a004	c002	4
a004	c003	2
a004	c008	2
a005	c002	2
a005	c005	2
a005	c006	2
a006	c001	4
a006	c002	4
a006	c003	2
a006	c007	2
a007	c001	1
a007	c002	2

a007	c030	2
a007	c032	4
a007	c005	2
a007	c006	2
a008	c028	2
a008	c029	2
a008	c030	2
a008	c037	4
a009	c003	4
a009	c008	4
a009	c037	4
a009	c031	2
a010	c038	2
a010	c029	2
a010	c031	2
a011	c005	2
a011	c002	4
a011	c008	2
a011	c031	2
a012	c037	2
a012	c002	2
a012	c004	3
a012	c007	3
a012	c030	3
a013	c037	2
a013	c038	2
a013	c029	2
a013	c030	2
a014	c006	4
a014	c003	4
a014	c001	4
a014	c030	4

Power module and its component table

hid	cid	cq
h001	c009	1
h001	c012	1
h001	c014	3
h001	c017	1
h002	c009	1
h002	c011	1
h002	c013	2
h002	c016	1
h003	c010	1
h003	c012	1
h003	c015	3
h003	c016	1
h004	c009	1
h004	c011	1
h004	c013	1

h004	c016	1
h005	c009	1
h005	c012	1
h005	c015	1
h005	c016	1
h006	c010	1
h006	c012	1
h006	c015	2
h006	c017	1
h007	c013	1
h007	c009	1
h007	c011	1
h007	c017	1
h008	c014	2
h008	c009	1
h008	c012	1
h008	c017	1
h009	c013	2
h009	c009	1
h009	c011	1
h009	c016	1
h009	c036	1
h010	c014	3
h010	c010	1
h010	c012	1
h010	c016	1
h011	c015	1
h011	c010	1
h011	c012	1
h011	c016	1
h011	c036	1
h012	c015	2
h012	c010	1
h012	c011	1
h012	c017	1
h013	c013	3
h013	c010	1
h013	c012	1
h013	c016	1
h013	c036	1
h014	c014	4
h014	c009	1
h014	c011	1
h014	c017	1
h015	c015	2
h015	c009	1
h015	c011	1
h015	c017	1

Top platform module and its component table

tid	cid	cq

t001	c018	1
t001	c025	1
t002	c019	1
t002	c025	1
t003	c019	1
t003	c022	1
t004	c018	1
t004	c023	1
t005	c018	1
t005	c025	1
t006	c018	1
t006	c026	1
t007	c018	1
t008	c026	1
t007	c023	1
t008	c041	1
t008	c022	1
t008	c033	1
t009	c018	2
t009	c026	2
t010	c041	2
t010	c023	2
t010	c026	2
t011	c019	2
t011	c025	1
t011	c033	1
t012	c041	4
t012	c023	1
t012	c026	1
t013	c041	1
t013	c026	1
t013	c023	1
t013	c033	1

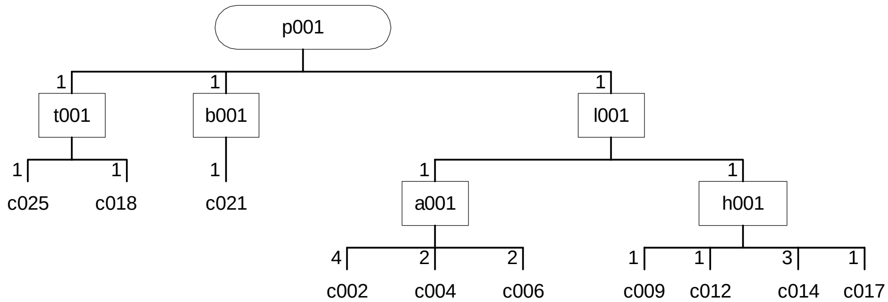
Base platform module and its component

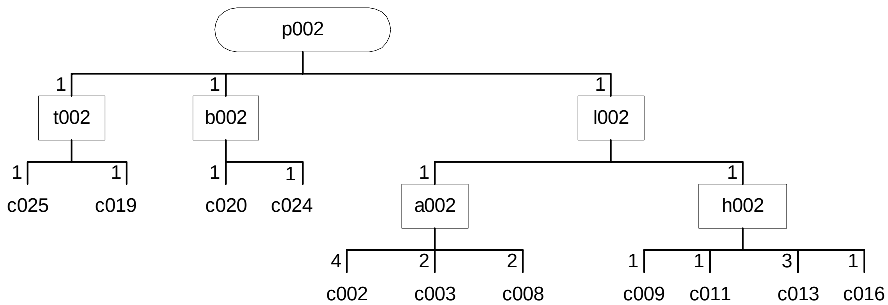
bid	cid	cq
b001	c021	1
b002	c020	1
b002	c024	1
b003	c020	1
b003	c024	1
b004	c020	1
b004	c027	1
b005	c021	1
b005	c024	1
b006	c021	1
b007	c040	2
b007	c027	1
b008	c039	1

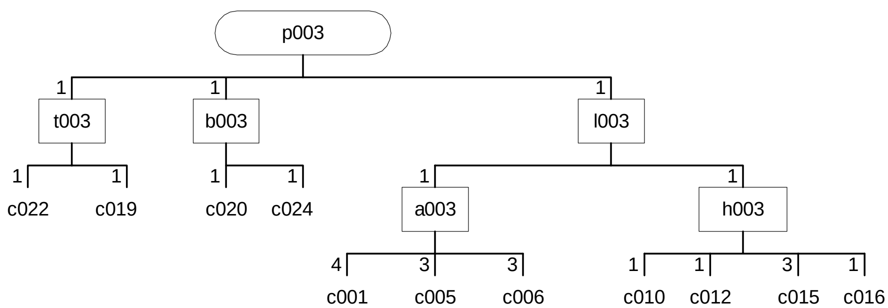
```
| b008 | c034 |     4 |
| b009 | c034 |     4 |
| b009 | c040 |     1 |
| b009 | c035 |     1 |
| b010 | c021 |     1 |
| b010 | c027 |     1 |
| b010 | c040 |     2 |
| b010 | c024 |     2 |
| b011 | c024 |     2 |
| b011 | c027 |     1 |
| b011 | c039 |     1 |
| b012 | c035 |     1 |
| b012 | c040 |     2 |
| b012 | c034 |     4 |
| b013 | c024 |     1 |
| b013 | c020 |     1 |
| b014 | c039 |     1 |
| b014 | c034 |     4 |
| b014 | c035 |     1 |
| b014 | c024 |     2 |
+------+------+-------+
```

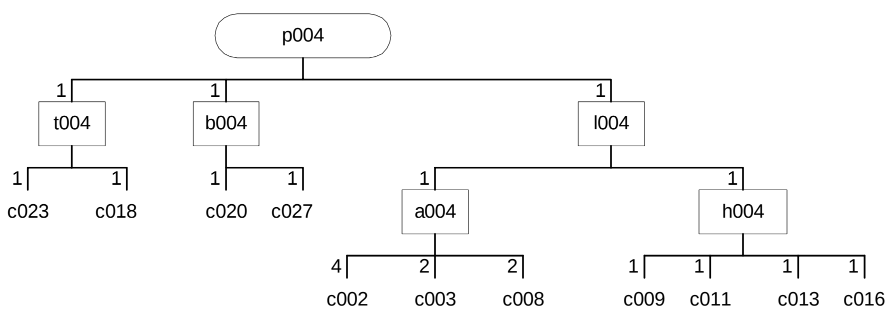
APPENDIX D

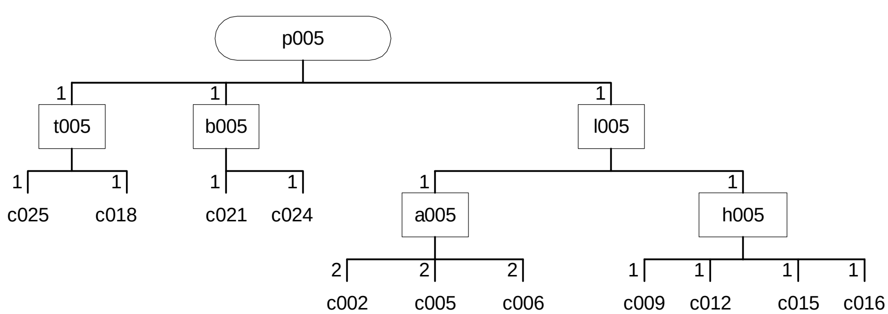
LIST OF LIFT PRODUCT STRUCTURE AND COMPONENT DATA IN XML DOCUMENT FORM

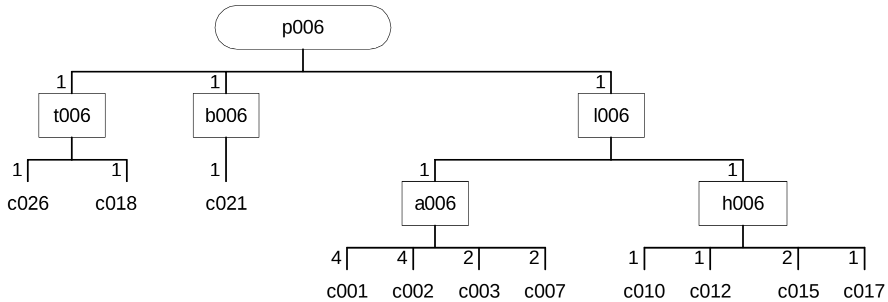

p001
1 t001 1 b001 1 l001
1 c025 1 c018 1 c021
1 a001 1 h001
4 c002 2 c004 2 c006
1 c009 1 c012 3 c014 1 c017

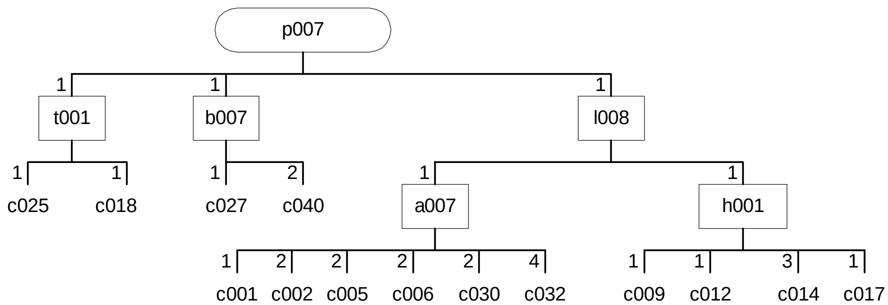

p002
1 t002 1 b002 1 l002
1 c025 1 c019 1 c020 1 c024
1 a002 1 h002
4 c002 2 c003 2 c008
1 c009 1 c011 3 c013 1 c016

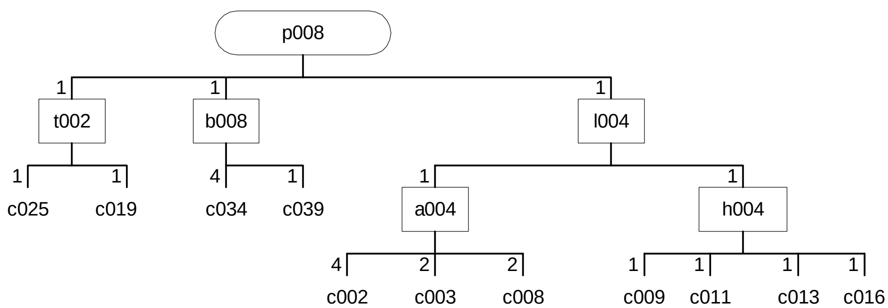

p003
1 t003 1 b003 1 l003
1 c022 1 c019 1 c020 1 c024
1 a003 1 h003
4 c001 3 c005 3 c006
1 c010 1 c012 3 c015 1 c016

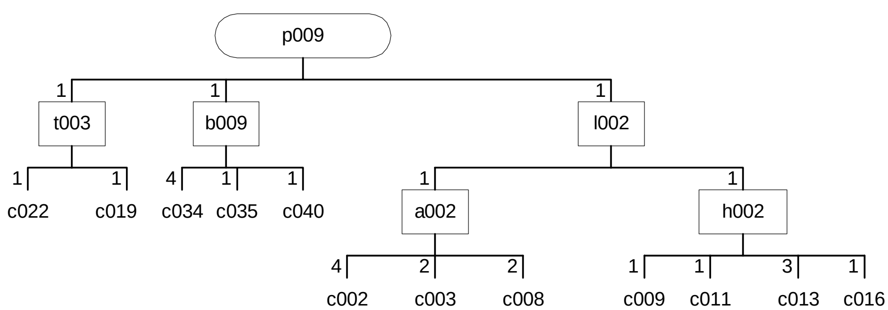

p004
1 t004 1 b004 1 l004
1 c023 1 c018 1 c020 1 c027
1 a004 1 h004
4 c002 2 c003 2 c008
1 c009 1 c011 1 c013 1 c016

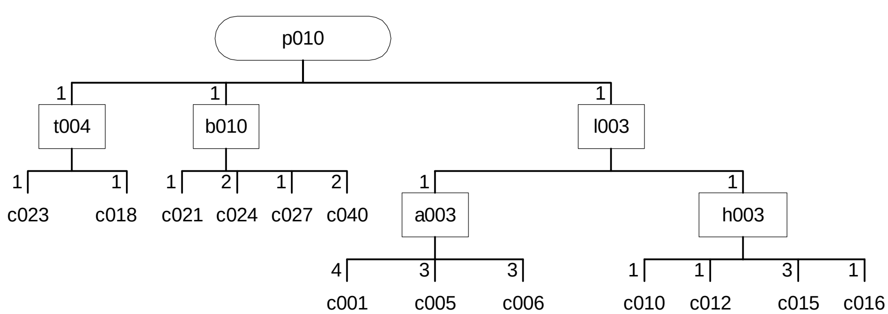

p005
1 t005 1 b005 1 l005
1 c025 1 c018 1 c021 1 c024
1 a005 1 h005
2 c002 2 c005 2 c006
1 c009 1 c012 1 c015 1 c016

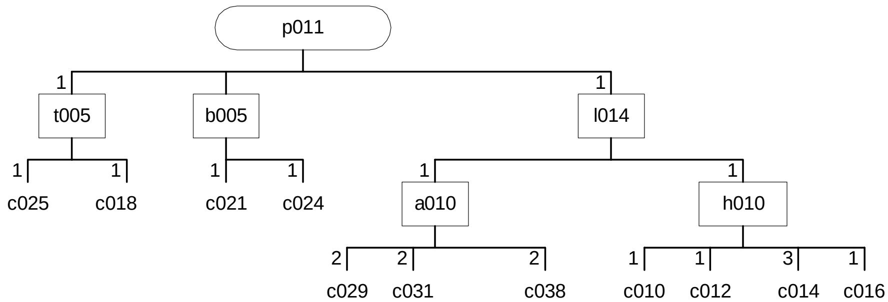

p006
t006
b006
l006
c026
c018
c021
a006
h006
c001
c002
c003
c007
c010
c012
c015
c017

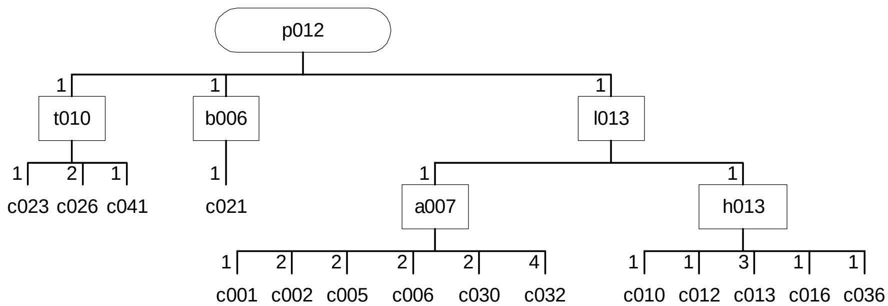

p007
t001
b007
l008
c025
c018
c027
c040
a007
h001
c001
c002
c005
c006
c030
c032
c009
c012
c014
c017

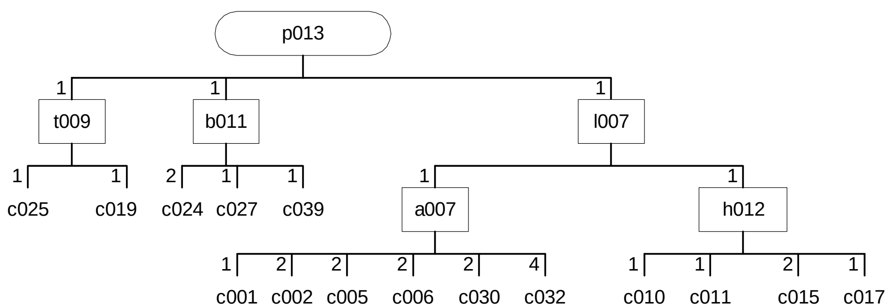

p008
t002
b008
l004
c025
c019
c034
c039
a004
h004
c002
c003
c008
c009
c011
c013
c016

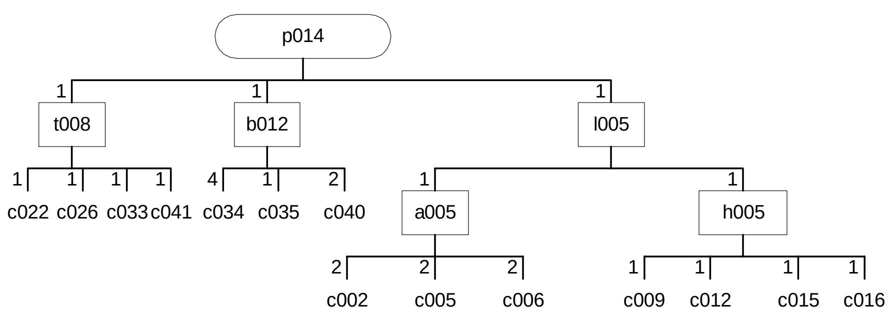

p009
t003
b009
l002
c022
c019
c034
c035
c040
a002
h002
c002
c003
c008
c009
c011
c013
c016

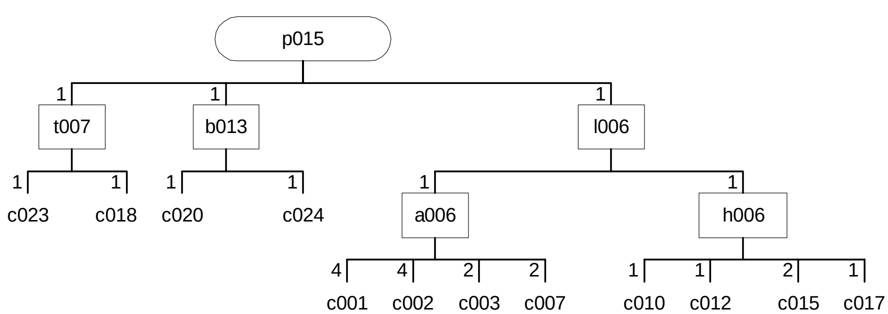

p010
t004
b010
l003
c023
c018
c021
c024
c027
c040
a003
h003
c001
c005
c006
c010
c012
c015
c016

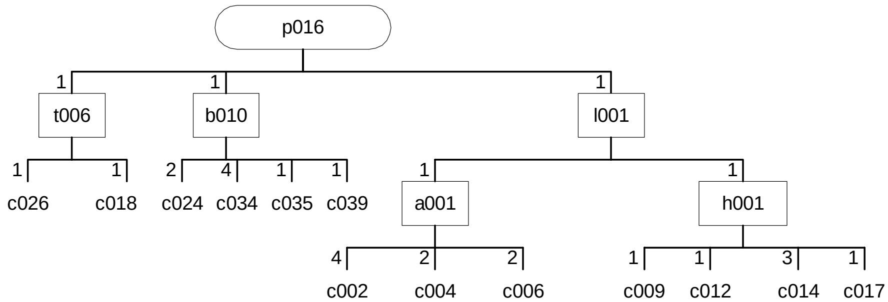

p011
1 t005
b005
1 l014
1 c025
1 c018
1 c021
1 c024
1 a010
1 h010
2 c029
2 c031
2 c038
1 c010
1 c012
3 c014
1 c016

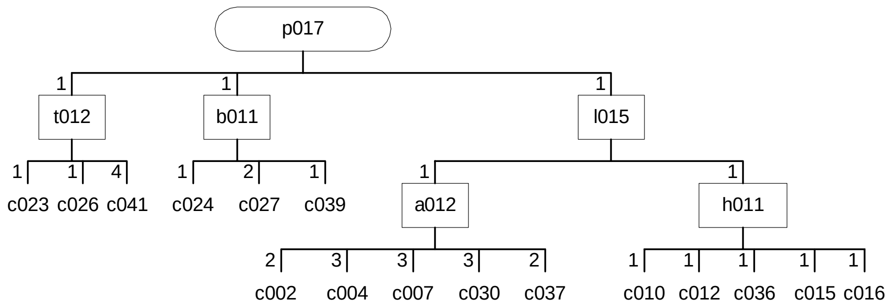

p012
1 t010
1 b006
1 l013
1 c023
2 c026
1 c041
1 c021
1 a007
1 h013
1 c001
2 c002
2 c005
2 c006
2 c030
4 c032
1 c010
1 c012
3 c013
1 c016
1 c036


p013
1 t009
1 b011
1 l007
1 c025
1 c019
2 c024
1 c027
1 c039
1 a007
1 h012
1 c001
2 c002
2 c005
2 c006
2 c030
4 c032
1 c010
1 c011
2 c015
1 c017


p014
1 t008
1 b012
1 l005
1 c022
1 c026
1 c033
1 c041
4 c034
1 c035
2 c040
1 a005
1 h005
2 c002
2 c005
2 c006
1 c009
1 c012
1 c015
1 c016


p015
1 t007
1 b013
1 l006
1 c023
1 c018
1 c020
1 c024
1 a006
1 h006
4 c001
4 c002
2 c003
2 c007
1 c010
1 c012
2 c015
1 c017


p016
1 1 1
t006 b010 l001
1 1 2 4 1 1 1 1
c026 c018 c024 c034 c035 c039 a001 h001
4 2 2 1 1 3 1
c002 c004 c006 c009 c012 c014 c017


p017
1 1 1
t012 b011 l015
1 1 4 1 2 1 1 1
c023 c026 c041 c024 c027 c039 a012 h011
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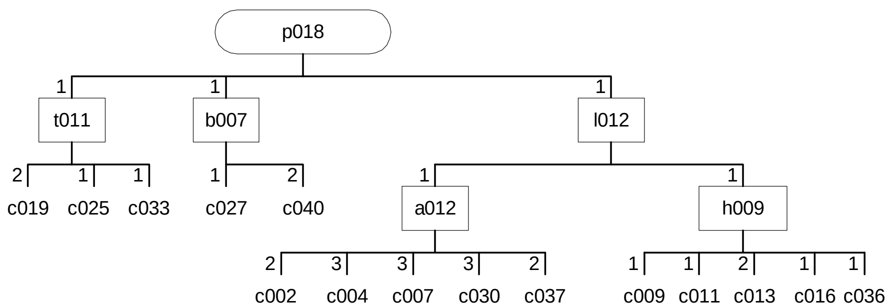
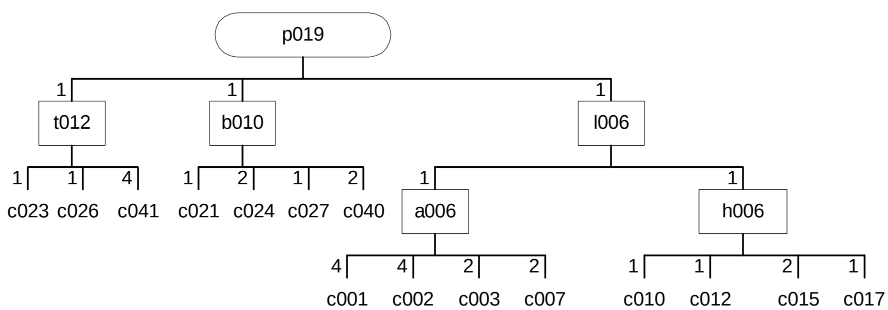
c002 c004 c007 c030 c037 c010 c012 c036 c015 c016


p018
1 1 1
t011 b007 l012
2 1 1 1 2 1 1
c019 c025 c033 c027 c040 a012 h009
2 3 3 3 2 1 1 2 1 1
c002 c004 c007 c030 c037 c009 c011 c013 c016 c036


p019
1 1 1
t012 b010 l006
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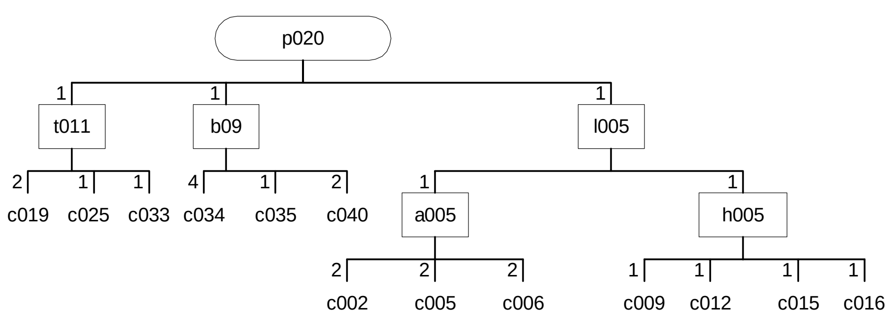
c001 c002 c003 c007 c010 c012 c015 c017


p020
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t011 b09 l005
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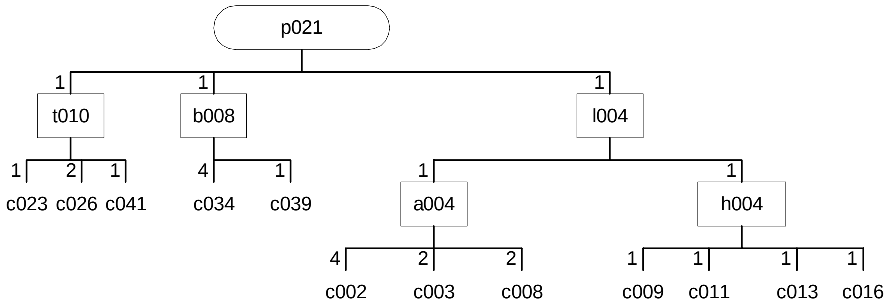
2 2 2 1 1 1 1
c002 c005 c006 c009 c012 c015 c016


p021
1 1 1
t010 b008 l004
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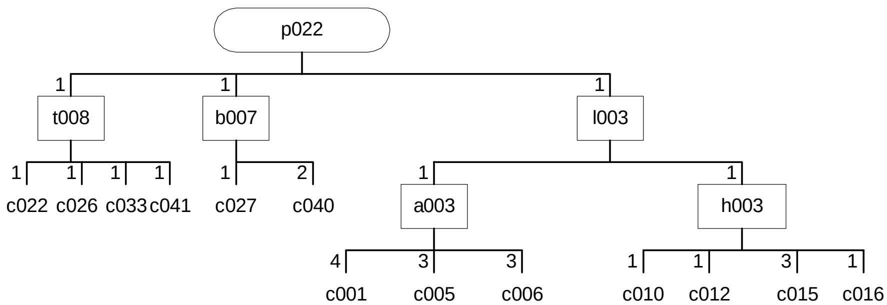
c023 c026 c041 c034 c039
a004 h004
4 2 2 1 1 1 1
c002 c003 c008 c009 c011 c013 c016


p022
1 1 1
t008 b007 l003
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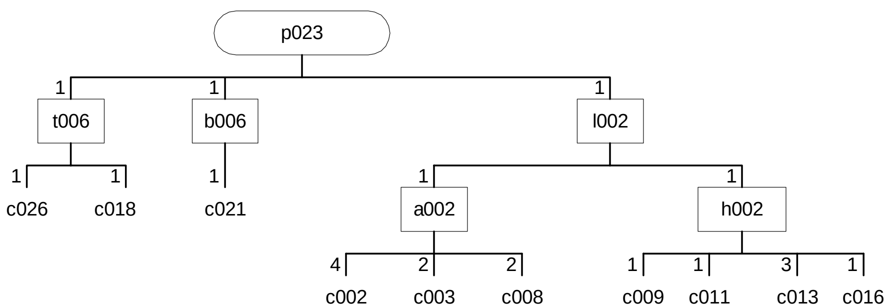
c022 c026 c033 c041 c027 c040
a003 h003
4 3 3 1 1 3 1
c001 c005 c006 c010 c012 c015 c016


p023
1 1 1
t006 b006 l002
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a002 h002
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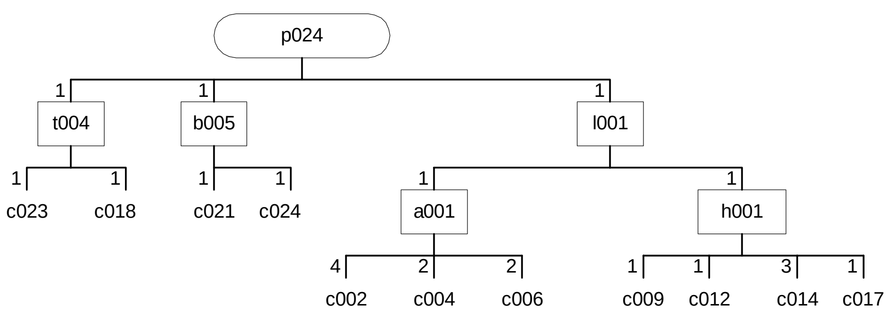
c002 c003 c008 c009 c011 c013 c016


p024
1 1 1
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c023 c018 c021 c024
a001 h001
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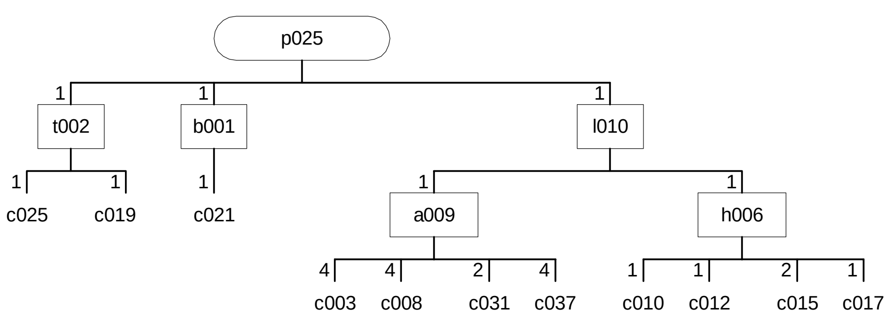
c002 c004 c006 c009 c012 c014 c017


p025
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t002 b001 l010
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a009 h006
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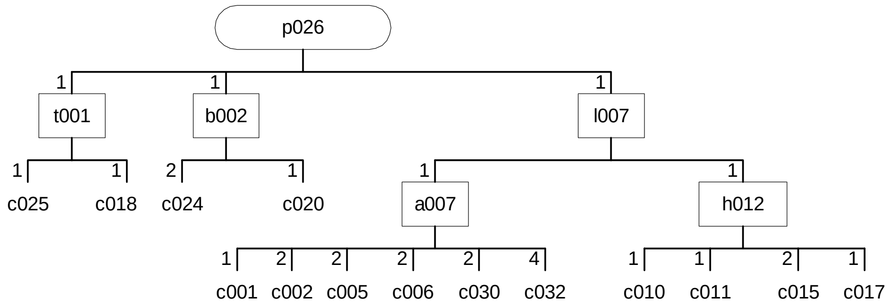
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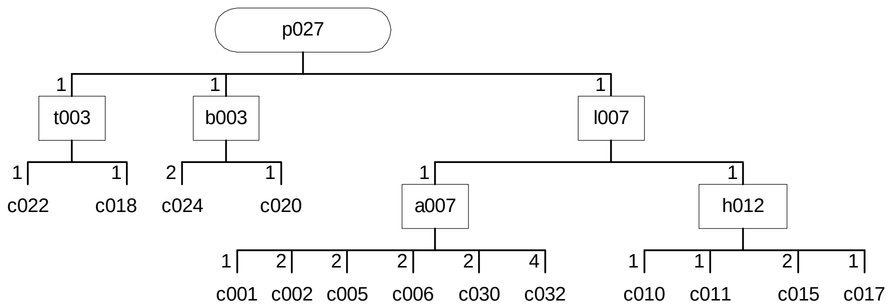
1 l007
1 c025
1 c018
2 c024
1 c020
1 a007
1 h012
1 c001
2 c002
2 c005
2 c006
2 c030
4 c032
1 c010
1 c011
2 c015
1 c017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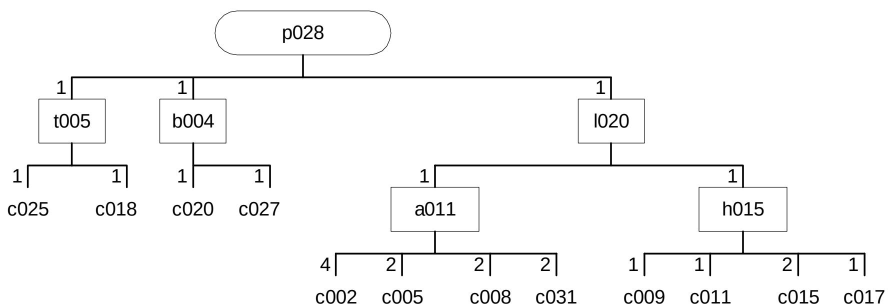
1 l007
1 c022
1 c018
2 c024
1 c020
1 a007
1 h012
1 c001
2 c002
2 c005
2 c006
2 c030
4 c032
1 c010
1 c011
2 c015
1 c017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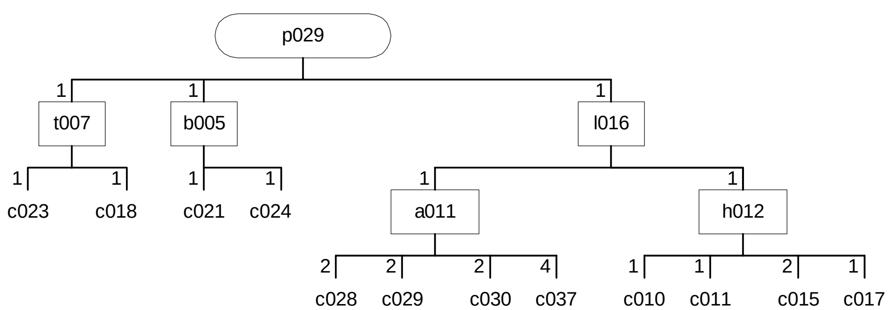
1 b004
1 l020
1 c025
1 c018
1 c020
1 c027
1 a011
1 h015
4 c002
2 c005
2 c008
2 c031
1 c009
1 c011
2 c015
1 c017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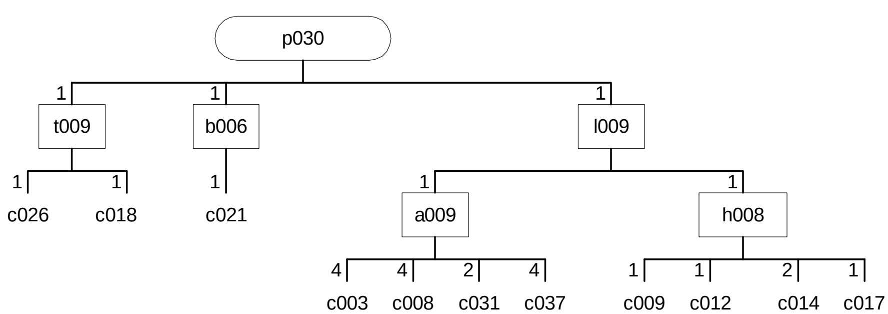
1 b005
1 l016
1 c023
1 c018
1 c021
1 c024
1 a011
1 h012
2 c028
2 c029
2 c030
4 c037
1 c010
1 c011
2 c015
1 c017


p030
1 t009
1 b006
1 l009
1 c026
1 c018
1 c021
1 a009
1 h008
4 c003
4 c008
2 c031
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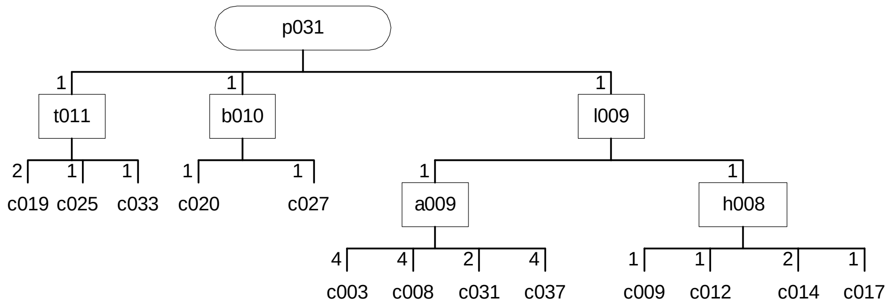
1 c012
2 c014
1 c017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c019 c025 c033 c020 c027
1 1
a009 h008
4 4 2 4 1 1 2 1
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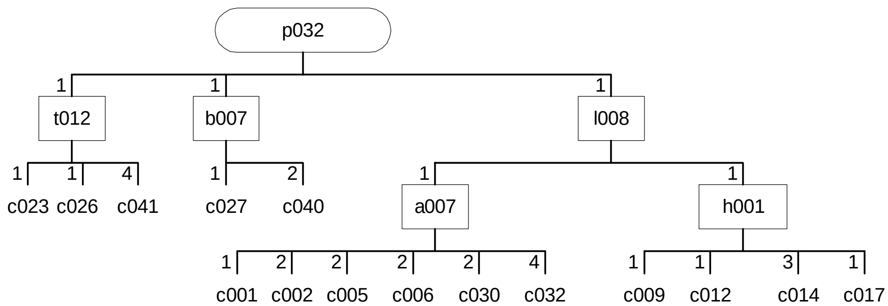
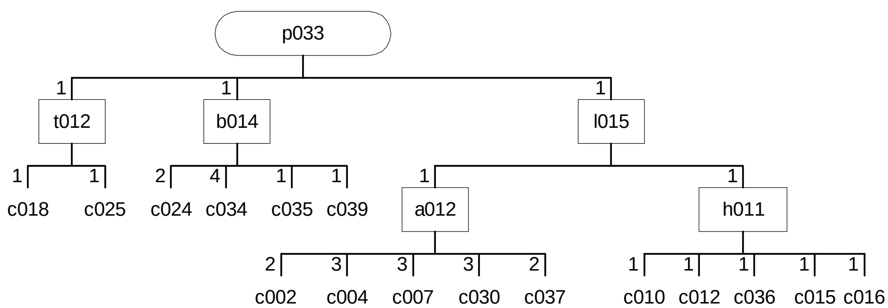

p032
1 1 1
t012 b007 l008
1 1 4 1 2
c023 c026 c041 c027 c040
1 1
a007 h001
1 2 2 2 2 4 1 1 3 1
c001 c002 c005 c006 c030 c032 c009 c012 c014 c017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t012 b014 l015
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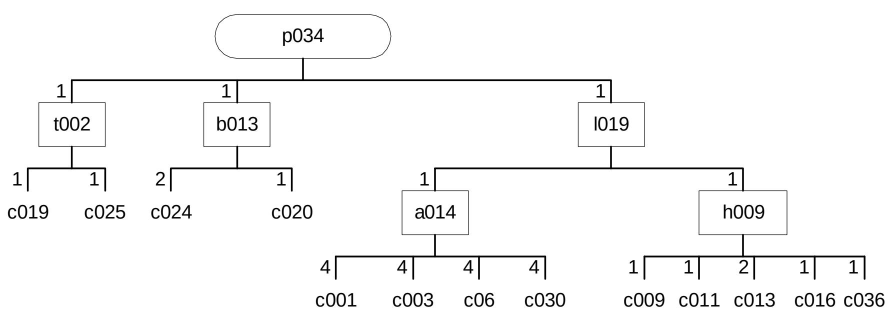
c018 c025 c024 c034 c035 c039
1 1
a012 h011
2 3 3 3 2 1 1 1 1 1
c002 c004 c007 c030 c037 c010 c012 c036 c015 c016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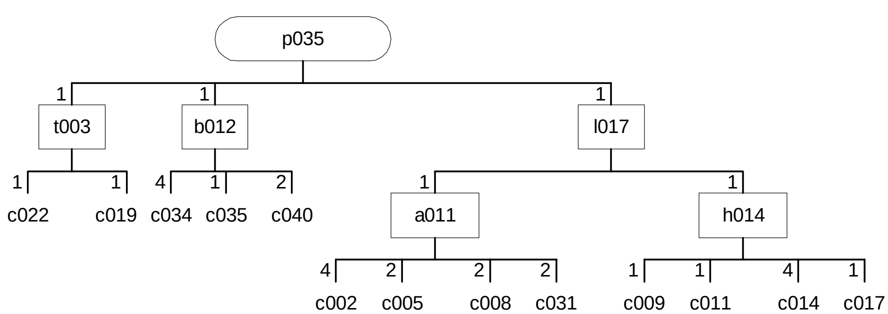
t002 b013 l019
1 1 2 1
c019 c025 c024 c020
1 1
a014 h009
4 4 4 4 1 1 2 1 1
c001 c003 c06 c030 c009 c011 c013 c016 c036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t003 b012 l017
1 1 4 1 2
c022 c019 c034 c035 c040
1 1
a011 h014
4 2 2 2 1 1 4 1
c002 c005 c008 c031 c009 c011 c014 c017

Lift product database in XML data document (LiftDB.xml)


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      <product id='p001'>
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            <unitprice>2000</unitprice>
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                  <component id='c018'>
                        <name>Platform TS</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c025'>
                        <name>Ball transfer top</name>
                        <quantity>1</quantity>
                  </component>
            </top_module>
            <base_module id='b001'>
                  <quantity>1</quantity>
                  <component id='c021'>
                        <name>Platform BL</name>
                        <quantity>1</quantity>
                  </component>
            </base_module>
            <lift_module id='l001'>
                  <quantity>1</quantity>
                  <arm_module id='a001'>
                        <quantity>1</quantity>
                        <component id='c002'>
                              <name>Stabilizer Type B</name>
                              <quantity>4</quantity>
                        </component>
                        <component id='c004'>
                              <name>Upper Lift Arm F</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c006'>
                              <name>Lower Lift Arm Type I</name>
                              <quantity>2</quantity>
                        </component>
                  </arm_module>
                  <power_module id='h001'>
                        <quantity>1</quantity>
                        <component id='c009'>
                              <name>Pump S</name>
                              <quantity>1</quantity>
                        </component>
                        <component id='c012'>
                              <name>Motor-Small</name>
                              <quantity>1</quantity>
                        </component>
```

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                        <component id='c014'>
                              <name>Hydraulic Cylinder M4</name>
                              <quantity>3</quantity>
                        </component>
                        <component id='c017'>
                              <name>Hydraulic Reservoir II</name>
                              <quantity>1</quantity>
                        </component>
                  </power_module>
            </lift_module>
      </product>
      <product id='p002'>
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            <unitprice>500</unitprice>
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                  <component id='c019'>
                        <name>Platform TM</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c025'>
                        <name>Ball transfer top</name>
                        <quantity>1</quantity>
                  </component>
            </top_module>
            <base_module id='b002'>
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                  <component id='c020'>
                        <name>Platform BM</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c024'>
                        <name>Fork Pocket</name>
                        <quantity>1</quantity>
                  </component>
            </base_module>
            <lift_module id='l002'>
                  <quantity>1</quantity>
                  <arm_module id='a002'>
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                        <component id='c002'>
                              <name>Stabilizer Type B</name>
                              <quantity>4</quantity>
                        </component>
                        <component id='c003'>
                              <name>Upper Lift Arm A</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c008'>
                              <name>Lower Lift Arm Type M</name>
                              <quantity>2</quantity>
                        </component>
                  </arm_module>
```

```
        <power_module id='h002'>
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              <component id='c011'>
                    <name>Motor-Large</name>
                    <quantity>1</quantity>
              </component>
              <component id='c013'>
                    <name>Hydraulic Cylinder M3</name>
                    <quantity>2</quantity>
              </component>
              <component id='c016'>
                    <name>Hydraulic Reservoir</name>
                    <quantity>1</quantity>
              </component>
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  </lift_module>
</product>
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        <component id='c019'>
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              <quantity>1</quantity>
        </component>
        <component id='c022'>
              <name>Turn table</name>
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        </component>
  </top_module>
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        <component id='c020'>
              <name>Platform BM</name>
              <quantity>1</quantity>
        </component>
        <component id='c024'>
              <name>Fork Pocket</name>
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        <arm_module id='a003'>
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                    <quantity>4</quantity>
```

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                  <quantity>3</quantity>
            </component>
            <component id='c006'>
                  <name>Lower Lift Arm Type I</name>
                  <quantity>3</quantity>
            </component>
      </arm_module>
      <power_module id='h003'>
            <quantity>1</quantity>
            <component id='c010'>
                  <name>Pump M</name>
                  <quantity>1</quantity>
            </component>
            <component id='c012'>
                  <name>Motor-Small</name>
                  <quantity>1</quantity>
            </component>
            <component id='c015'>
                  <name>Hydraulic Cylinder M5</name>
                  <quantity>3</quantity>
            </component>
            <component id='c016'>
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                  <quantity>1</quantity>
            </component>
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   </lift_module>
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            <quantity>1</quantity>
      </component>
      <component id='c023'>
            <name>Tilting Top</name>
            <quantity>1</quantity>
      </component>
   </top_module>
   <base_module id='b004'>
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      <component id='c020'>
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            <quantity>1</quantity>
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      <component id='c027'>
            <name>Toe sensor</name>
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                    &lt;quantity&gt;4&lt;/quantity&gt;
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            &lt;power_module id='h004'&gt;
                &lt;quantity&gt;1&lt;/quantity&gt;
                &lt;component id='c009'&gt;
                    &lt;name&gt;Pump S&lt;/name&gt;
                    &lt;quantity&gt;1&lt;/quantity&gt;
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                    &lt;quantity&gt;1&lt;/quantity&gt;
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                    &lt;name&gt;Hydraulic Cylinder M3&lt;/name&gt;
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        &lt;/lift_module&gt;
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                &lt;quantity&gt;1&lt;/quantity&gt;
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```
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            <arm_module id='a005'>
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                <component id='c002'>
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                    <quantity>2</quantity>
                </component>
                <component id='c005'>
                    <name>Upper Lift Arm W</name>
                    <quantity>2</quantity>
                </component>
                <component id='c006'>
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                    <quantity>2</quantity>
                </component>
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                </component>
                <component id='c012'>
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                    <quantity>1</quantity>
                </component>
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                  &lt;quantity&gt;1&lt;/quantity&gt;
            &lt;/component&gt;
            &lt;component id='c012'&gt;
                  &lt;name&gt;Motor-Small&lt;/name&gt;
                  &lt;quantity&gt;1&lt;/quantity&gt;
            &lt;/component&gt;
            &lt;component id='c015'&gt;
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                  &lt;quantity&gt;2&lt;/quantity&gt;
            &lt;/component&gt;
```

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            </component>
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            <component id='c027'>
                <name>Toe sensor</name>
                <quantity>1</quantity>
            </component>
            <component id='c040'>
                <name>Platform BN</name>
                <quantity>2</quantity>
            </component>
        </base_module>
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            <arm_module id='a007'>
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                    <quantity>1</quantity>
                </component>
                <component id='c002'>
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                    <quantity>2</quantity>
                </component>
                <component id='c005'>
                    <name>Upper Lift Arm W</name>
                    <quantity>2</quantity>
                </component>
                <component id='c006'>
                    <name>Lower Lift Arm Type I</name>
                    <quantity>2</quantity>
                </component>
                <component id='c030'>
```

```
                        <name>Lift Arm Axle T</name>
                        <quantity>2</quantity>
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                  <component id='c032'>
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                        <quantity>4</quantity>
                  </component>
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            <power_module id='h001'>
                  <quantity>1</quantity>
                  <component id='c009'>
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                        <quantity>1</quantity>
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                  <component id='c012'>
                        <name>Motor-Small</name>
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                  </component>
                  <component id='c014'>
                        <name>Hydraulic Cylinder M4</name>
                        <quantity>3</quantity>
                  </component>
                  <component id='c017'>
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                        <quantity>1</quantity>
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      </lift_module>
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                  <quantity>1</quantity>
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            <component id='c025'>
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                  <quantity>1</quantity>
            </component>
      </top_module>
      <base_module id='b008'>
            <quantity>1</quantity>
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                  <name>Flange Wheel</name>
                  <quantity>4</quantity>
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            <component id='c039'>
                  <name>Platform BW</name>
                  <quantity>1</quantity>
            </component>
```

```
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					&lt;quantity&gt;4&lt;/quantity&gt;
				&lt;/component&gt;
				&lt;component id='c003'&gt;
					&lt;name&gt;Upper Lift Arm A&lt;/name&gt;
					&lt;quantity&gt;2&lt;/quantity&gt;
				&lt;/component&gt;
				&lt;component id='c008'&gt;
					&lt;name&gt;Lower Lift Arm Type M&lt;/name&gt;
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			&lt;/arm_module&gt;
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				&lt;quantity&gt;1&lt;/quantity&gt;
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					&lt;quantity&gt;1&lt;/quantity&gt;
				&lt;/component&gt;
				&lt;component id='c011'&gt;
					&lt;name&gt;Motor-Large&lt;/name&gt;
					&lt;quantity&gt;1&lt;/quantity&gt;
				&lt;/component&gt;
				&lt;component id='c013'&gt;
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				&lt;/component&gt;
				&lt;component id='c016'&gt;
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			&lt;quantity&gt;1&lt;/quantity&gt;
			&lt;component id='c019'&gt;
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				&lt;quantity&gt;1&lt;/quantity&gt;
			&lt;/component&gt;
			&lt;component id='c022'&gt;
				&lt;name&gt;Turn table&lt;/name&gt;
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			&lt;/component&gt;
		&lt;/top_module&gt;
```

```
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            </component>
            <component id='c035'>
                  <name>Push Bar</name>
                  <quantity>1</quantity>
            </component>
            <component id='c040'>
                  <name>Platform BN</name>
                  <quantity>1</quantity>
            </component>
      </base_module>
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            <quantity>1</quantity>
            <arm_module id='a002'>
                  <quantity>1</quantity>
                  <component id='c002'>
                        <name>Stabilizer Type B</name>
                        <quantity>4</quantity>
                  </component>
                  <component id='c003'>
                        <name>Upper Lift Arm A</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c008'>
                        <name>Lower Lift Arm Type M</name>
                        <quantity>2</quantity>
                  </component>
            </arm_module>
            <power_module id='h002'>
                  <quantity>1</quantity>
                  <component id='c009'>
                        <name>Pump S</name>
                        <quantity>1</quantity>
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                  <component id='c011'>
                        <name>Motor-Large</name>
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                  </component>
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                        <quantity>2</quantity>
                  </component>
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                        <quantity>1</quantity>
                  </component>
            </power_module>
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</product>
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```

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            <quantity>1</quantity>
      </component>
      <component id='c023'>
            <name>Tilting Top</name>
            <quantity>1</quantity>
      </component>
</top_module>
<base_module id='b010'>
      <quantity>1</quantity>
      <component id='c021'>
            <name>Platform BL</name>
            <quantity>1</quantity>
      </component>
      <component id='c024'>
            <name>Fork Pocket</name>
            <quantity>2</quantity>
      </component>
      <component id='c027'>
            <name>Toe sensor</name>
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      </component>
      <component id='c040'>
            <name>Platform BN</name>
            <quantity>2</quantity>
      </component>
</base_module>
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      <arm_module id='a003'>
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            <component id='c001'>
                  <name>Stabilizer Type A</name>
                  <quantity>4</quantity>
            </component>
            <component id='c005'>
                  <name>Upper Lift Arm W</name>
                  <quantity>3</quantity>
            </component>
            <component id='c006'>
                  <name>Lower Lift Arm Type I</name>
                  <quantity>3</quantity>
            </component>
      </arm_module>
      <power_module id='h003'>
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                  <name>Pump M</name>
```

```
                        <quantity>1</quantity>
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                        <quantity>1</quantity>
                  </component>
                  <component id='c015'>
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                        <quantity>3</quantity>
                  </component>
                  <component id='c016'>
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                        <quantity>1</quantity>
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</product>
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            <component id='c025'>
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            <component id='c021'>
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            </component>
            <component id='c024'>
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                  <quantity>1</quantity>
            </component>
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                        <quantity>2</quantity>
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                  <component id='c031'>
                        <name>Lift Arm Axle M</name>
                        <quantity>2</quantity>
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                </component>
                <component id='c038'>
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                </component>
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            <power_module id='h010'>
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                <component id='c010'>
                    <name>Pump M</name>
                    <quantity>1</quantity>
                </component>
                <component id='c012'>
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                </component>
                <component id='c014'>
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                </component>
                <component id='c016'>
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                    <quantity>1</quantity>
                </component>
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            </component>
            <component id='c026'>
                <name>Antiskid top</name>
                <quantity>2</quantity>
            </component>
            <component id='c041'>
                <name>Platform TG</name>
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            </component>
        </base_module>
        <lift_module id='l013'>
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```
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                        <quantity>1</quantity>
                  </component>
                  <component id='c002'>
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                        <quantity>2</quantity>
                  </component>
                  <component id='c005'>
                        <name>Upper Lift Arm W</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c006'>
                        <name>Lower Lift Arm Type I</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c030'>
                        <name>Lift Arm Axle T</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c032'>
                        <name>Stabilizer Leg</name>
                        <quantity>4</quantity>
                  </component>
            </arm_module>
            <power_module id='h013'>
                  <quantity>1</quantity>
                  <component id='c010'>
                        <name>Pump M</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c012'>
                        <name>Motor-Small</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c013'>
                        <name>Hydraulic Cylinder M3</name>
                        <quantity>3</quantity>
                  </component>
                  <component id='c016'>
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                        <quantity>1</quantity>
                  </component>
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      </lift_module>
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            <quantity>2</quantity>
      </component>
      <component id='c026'>
            <name>Antiskid top</name>
            <quantity>2</quantity>
      </component>
</top_module>
<base_module id='b011'>
      <quantity>1</quantity>
      <component id='c024'>
            <name>Fork Pocket</name>
            <quantity>2</quantity>
      </component>
      <component id='c027'>
            <name>Toe sensor</name>
            <quantity>1</quantity>
      </component>
      <component id='c039'>
            <name>Platform BW</name>
            <quantity>1</quantity>
      </component>
</base_module>
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      <arm_module id='a007'>
            <quantity>1</quantity>
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            </component>
            <component id='c002'>
                  <name>Stabilizer Type B</name>
                  <quantity>2</quantity>
            </component>
            <component id='c005'>
                  <name>Upper Lift Arm W</name>
                  <quantity>2</quantity>
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            <component id='c006'>
                  <name>Lower Lift Arm Type I</name>
                  <quantity>2</quantity>
            </component>
            <component id='c030'>
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                  <quantity>2</quantity>
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            <component id='c032'>
```

```
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                    &lt;component id='c010'&gt;
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                    &lt;/component&gt;
                    &lt;component id='c011'&gt;
                        &lt;name&gt;Motor-Large&lt;/name&gt;
                        &lt;quantity&gt;1&lt;/quantity&gt;
                    &lt;/component&gt;
                    &lt;component id='c015'&gt;
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                        &lt;quantity&gt;2&lt;/quantity&gt;
                    &lt;/component&gt;
                    &lt;component id='c017'&gt;
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            &lt;/lift_module&gt;
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                &lt;component id='c022'&gt;
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                &lt;/component&gt;
                &lt;component id='c026'&gt;
                    &lt;name&gt;Antiskid top&lt;/name&gt;
                    &lt;quantity&gt;1&lt;/quantity&gt;
                &lt;/component&gt;
                &lt;component id='c033'&gt;
                    &lt;name&gt;Hand Rail&lt;/name&gt;
                    &lt;quantity&gt;1&lt;/quantity&gt;
                &lt;/component&gt;
                &lt;component id='c041'&gt;
                    &lt;name&gt;Platform TG&lt;/name&gt;
                    &lt;quantity&gt;1&lt;/quantity&gt;
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            &lt;base_module id='b012'&gt;
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                    &lt;quantity&gt;4&lt;/quantity&gt;
                &lt;/component&gt;
```

```
            <component id='c035'>
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            <component id='c040'>
                <name>Platform BN</name>
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            </component>
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                </component>
                <component id='c005'>
                    <name>Upper Lift Arm W</name>
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                <component id='c006'>
                    <name>Lower Lift Arm Type I</name>
                    <quantity>2</quantity>
                </component>
            </arm_module>
            <power_module id='h005'>
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                    <quantity>1</quantity>
                </component>
                <component id='c012'>
                    <name>Motor-Small</name>
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                </component>
                <component id='c015'>
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                    <quantity>1</quantity>
                </component>
                <component id='c016'>
                    <name>Hydraulic Reservoir</name>
                    <quantity>1</quantity>
                </component>
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        </lift_module>
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```
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        </component>
        <component id='c023'>
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        </component>
    </top_module>
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        <component id='c020'>
            <name>Platform BM</name>
            <quantity>1</quantity>
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        <component id='c024'>
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        <arm_module id='a006'>
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            <component id='c002'>
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            </component>
            <component id='c003'>
                <name>Upper Lift Arm A</name>
                <quantity>2</quantity>
            </component>
            <component id='c007'>
                <name>Lower Lift Arm Type T</name>
                <quantity>2</quantity>
            </component>
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        <power_module id='h006'>
            <quantity>1</quantity>
            <component id='c010'>
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                <quantity>1</quantity>
            </component>
            <component id='c012'>
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```

```
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    </lift_module>
</product>
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        </component>
        <component id='c026'>
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        <quantity>1</quantity>
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```

```
                <name>Lower Lift Arm Type I</name>
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        <component id='c041'>
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      </component>
      <component id='c033'>
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      </component>
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```

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			<component id='c003'>
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			<component id='c009'>
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			</component>
			<component id='c011'>
				<name>Motor-Large</name>
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            &lt;/component&gt;
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			</component>
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		<component id='c019'>
			<name>Platform TM</name>
			<quantity>1</quantity>
		</component>
		<component id='c022'>
```

```
            <name>Turn table</name>
            <quantity>1</quantity>
      </component>
</top_module>
<base_module id='b003'>
      <quantity>1</quantity>
      <component id='c020'>
            <name>Platform BM</name>
            <quantity>1</quantity>
      </component>
      <component id='c024'>
            <name>Fork Pocket</name>
            <quantity>1</quantity>
      </component>
</base_module>
<lift_module id='l007'>
      <quantity>1</quantity>
      <arm_module id='a007'>
            <quantity>1</quantity>
            <component id='c001'>
                  <name>Stabilizer Type A</name>
                  <quantity>1</quantity>
            </component>
            <component id='c002'>
                  <name>Stabilizer Type B</name>
                  <quantity>2</quantity>
            </component>
            <component id='c005'>
                  <name>Upper Lift Arm W</name>
                  <quantity>2</quantity>
            </component>
            <component id='c006'>
                  <name>Lower Lift Arm Type I</name>
                  <quantity>2</quantity>
            </component>
            <component id='c030'>
                  <name>Lift Arm Axle T</name>
                  <quantity>2</quantity>
            </component>
            <component id='c032'>
                  <name>Stabilizer Leg</name>
                  <quantity>4</quantity>
            </component>
      </arm_module>
      <power_module id='h012'>
            <quantity>1</quantity>
            <component id='c010'>
                  <name>Pump M</name>
                  <quantity>1</quantity>
            </component>
            <component id='c011'>
                  <name>Motor-Large</name>
                  <quantity>1</quantity>
            </component>
```

```
            &lt;component id='c015'&gt;
                  &lt;name&gt;Hydraulic Cylinder M5&lt;/name&gt;
                  &lt;quantity&gt;2&lt;/quantity&gt;
            &lt;/component&gt;
            &lt;component id='c017'&gt;
                  &lt;name&gt;Hydraulic Reservoir II&lt;/name&gt;
                  &lt;quantity&gt;1&lt;/quantity&gt;
            &lt;/component&gt;
      &lt;/power_module&gt;
   &lt;/lift_module&gt;
&lt;/product&gt;
&lt;product id='p028'&gt;
   &lt;name&gt;Product No. 28&lt;/name&gt;
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   &lt;unitprice&gt;480&lt;/unitprice&gt;
   &lt;top_module id='t005'&gt;
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      &lt;component id='c018'&gt;
            &lt;name&gt;Platform TS&lt;/name&gt;
            &lt;quantity&gt;1&lt;/quantity&gt;
      &lt;/component&gt;
      &lt;component id='c025'&gt;
            &lt;name&gt;Ball transfer top&lt;/name&gt;
            &lt;quantity&gt;1&lt;/quantity&gt;
      &lt;/component&gt;
   &lt;/top_module&gt;
   &lt;base_module id='b004'&gt;
      &lt;quantity&gt;1&lt;/quantity&gt;
      &lt;component id='c020'&gt;
            &lt;name&gt;Platform BM&lt;/name&gt;
            &lt;quantity&gt;1&lt;/quantity&gt;
      &lt;/component&gt;
      &lt;component id='c027'&gt;
            &lt;name&gt;Toe sensor&lt;/name&gt;
            &lt;quantity&gt;1&lt;/quantity&gt;
      &lt;/component&gt;
   &lt;/base_module&gt;
   &lt;lift_module id='l020'&gt;
      &lt;quantity&gt;1&lt;/quantity&gt;
      &lt;arm_module id='a011'&gt;
            &lt;quantity&gt;1&lt;/quantity&gt;
            &lt;component id='c002'&gt;
                  &lt;name&gt;Stabilizer Type B&lt;/name&gt;
                  &lt;quantity&gt;4&lt;/quantity&gt;
            &lt;/component&gt;
            &lt;component id='c005'&gt;
                  &lt;name&gt;Upper Lift Arm W&lt;/name&gt;
                  &lt;quantity&gt;2&lt;/quantity&gt;
            &lt;/component&gt;
            &lt;component id='c008'&gt;
                  &lt;name&gt;Lower Lift Arm Type M&lt;/name&gt;
                  &lt;quantity&gt;2&lt;/quantity&gt;
            &lt;/component&gt;
            &lt;component id='c031'&gt;
```

```
                <name>Lift Arm Axle M</name>
                <quantity>2</quantity>
            </component>
        </arm_module>
        <power_module id='h015'>
            <quantity>1</quantity>
            <component id='c009'>
                <name>Pump S</name>
                <quantity>1</quantity>
            </component>
            <component id='c011'>
                <name>Motor-Large</name>
                <quantity>1</quantity>
            </component>
            <component id='c015'>
                <name>Hydraulic Cylinder M5</name>
                <quantity>2</quantity>
            </component>
            <component id='c017'>
                <name>Hydraulic Reservoir II</name>
                <quantity>1</quantity>
            </component>
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    </lift_module>
</product>
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    <inventory>92</inventory>
    <unitprice>590</unitprice>
    <top_module id='t007'>
        <quantity>1</quantity>
        <component id='c018'>
            <name>Platform TS</name>
            <quantity>1</quantity>
        </component>
        <component id='c023'>
            <name>Tilting Top</name>
            <quantity>1</quantity>
        </component>
    </top_module>
    <base_module id='b005'>
        <quantity>1</quantity>
        <component id='c021'>
            <name>Platform BL</name>
            <quantity>1</quantity>
        </component>
        <component id='c024'>
            <name>Fork Pocket</name>
            <quantity>1</quantity>
        </component>
    </base_module>
    <lift_module id='l016'>
        <quantity>1</quantity>
        <arm_module id='a008'>
```

```
                        <quantity>1</quantity>
                        <component id='c028'>
                              <name>Outer Lift Arm XL</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c029'>
                              <name>Inner Lift Arm T8</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c030'>
                              <name>Lift Arm Axle T</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c037'>
                              <name>Stabilizer Type K</name>
                              <quantity>4</quantity>
                        </component>
                  </arm_module>
                  <power_module id='h013'>
                        <quantity>1</quantity>
                        <component id='c010'>
                              <name>Pump M</name>
                              <quantity>1</quantity>
                        </component>
                        <component id='c012'>
                              <name>Motor-Small</name>
                              <quantity>1</quantity>
                        </component>
                        <component id='c013'>
                              <name>Hydraulic Cylinder M3</name>
                              <quantity>3</quantity>
                        </component>
                        <component id='c016'>
                              <name>Hydraulic Reservoir</name>
                              <quantity>1</quantity>
                        </component>
                        <component id='c036'>
                              <name>DC power unit</name>
                              <quantity>1</quantity>
                        </component>
                  </power_module>
            </lift_module>
      </product>
      <product id='p030'>
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            <unitprice>990</unitprice>
            <top_module id='t009'>
                  <quantity>1</quantity>
                  <component id='c018'>
                        <name>Platform TS</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c026'>
```

```
                  <name>Antiskid top</name>
                  <quantity>2</quantity>
            </component>
      </top_module>
      <base_module id='b006'>
            <quantity>1</quantity>
            <component id='c021'>
                  <name>Platform BL</name>
                  <quantity>1</quantity>
            </component>
      </base_module>
      <lift_module id='l011'>
            <quantity>1</quantity>
            <arm_module id='a009'>
                  <quantity>1</quantity>
                  <component id='c003'>
                        <name>Upper Lift Arm A</name>
                        <quantity>4</quantity>
                  </component>
                  <component id='c008'>
                        <name>Lower Lift Arm Type M</name>
                        <quantity>4</quantity>
                  </component>
                  <component id='c031'>
                        <name>Lift Arm Axle M</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c037'>
                        <name>Stabilizer Type K</name>
                        <quantity>4</quantity>
                  </component>
            </arm_module>
            <power_module id='h008'>
                  <quantity>1</quantity>
                  <component id='c009'>
                        <name>Pump S</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c012'>
                        <name>Motor-Small</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c014'>
                        <name>Hydraulic Cylinder M4</name>
                        <quantity>2</quantity>
                  </component>
                  <component id='c017'>
                        <name>Hydraulic Reservoir II</name>
                        <quantity>1</quantity>
                  </component>
            </power_module>
      </lift_module>
</product>
<product id='p031'>
```

```
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            <name>Platform TM</name>
            <quantity>2</quantity>
      </component>
      <component id='c025'>
            <name>Ball transfer top</name>
            <quantity>1</quantity>
      </component>
      <component id='c033'>
            <name>Hand Rail</name>
            <quantity>1</quantity>
      </component>
</top_module>
<base_module id='b004'>
      <quantity>1</quantity>
      <component id='c020'>
            <name>Platform BM</name>
            <quantity>1</quantity>
      </component>
      <component id='c027'>
            <name>Toe sensor</name>
            <quantity>1</quantity>
      </component>
</base_module>
<lift_module id='l011'>
      <quantity>1</quantity>
      <arm_module id='a009'>
            <quantity>1</quantity>
            <component id='c003'>
                  <name>Upper Lift Arm A</name>
                  <quantity>4</quantity>
            </component>
            <component id='c008'>
                  <name>Lower Lift Arm Type M</name>
                  <quantity>4</quantity>
            </component>
            <component id='c031'>
                  <name>Lift Arm Axle M</name>
                  <quantity>2</quantity>
            </component>
            <component id='c037'>
                  <name>Stabilizer Type K</name>
                  <quantity>4</quantity>
            </component>
      </arm_module>
      <power_module id='h008'>
            <quantity>1</quantity>
            <component id='c009'>
                  <name>Pump S</name>
```

```
                    <quantity>1</quantity>
                </component>
                <component id='c012'>
                    <name>Motor-Small</name>
                    <quantity>1</quantity>
                </component>
                <component id='c014'>
                    <name>Hydraulic Cylinder M4</name>
                    <quantity>2</quantity>
                </component>
                <component id='c017'>
                    <name>Hydraulic Reservoir II</name>
                    <quantity>1</quantity>
                </component>
            </power_module>
        </lift_module>
    </product>
    <product id='p032'>
        <name>Product No. 32</name>
        <inventory>97</inventory>
        <unitprice>400</unitprice>
        <top_module id='t012'>
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            <component id='c023'>
                <name>Tilting Top</name>
                <quantity>1</quantity>
            </component>
            <component id='c026'>
                <name>Antiskid top</name>
                <quantity>1</quantity>
            </component>
            <component id='c041'>
                <name>Platform TG</name>
                <quantity>4</quantity>
            </component>
        </top_module>
        <base_module id='b007'>
            <quantity>1</quantity>
            <component id='c027'>
                <name>Toe sensor</name>
                <quantity>1</quantity>
            </component>
            <component id='c040'>
                <name>Platform BN</name>
                <quantity>2</quantity>
            </component>
        </base_module>
        <lift_module id='l008'>
            <quantity>1</quantity>
            <arm_module id='a007'>
                <quantity>1</quantity>
                <component id='c001'>
                    <name>Stabilizer Type A</name>
                    <quantity>1</quantity>
```

```
                        </component>
                        <component id='c002'>
                              <name>Stabilizer Type B</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c005'>
                              <name>Upper Lift Arm W</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c006'>
                              <name>Lower Lift Arm Type I</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c030'>
                              <name>Lift Arm Axle T</name>
                              <quantity>2</quantity>
                        </component>
                        <component id='c032'>
                              <name>Stabilizer Leg</name>
                              <quantity>4</quantity>
                        </component>
                  </arm_module>
                  <power_module id='h001'>
                        <quantity>1</quantity>
                        <component id='c009'>
                              <name>Pump S</name>
                              <quantity>1</quantity>
                        </component>
                        <component id='c012'>
                              <name>Motor-Small</name>
                              <quantity>1</quantity>
                        </component>
                        <component id='c014'>
                              <name>Hydraulic Cylinder M4</name>
                              <quantity>3</quantity>
                        </component>
                        <component id='c017'>
                              <name>Hydraulic Reservoir II</name>
                              <quantity>1</quantity>
                        </component>
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            </lift_module>
      </product>
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                  <component id='c018'>
                        <name>Platform TS</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c025'>
```

```
            <name>Ball transfer top</name>
            <quantity>1</quantity>
      </component>
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      <component id='c024'>
            <name>Fork Pocket</name>
            <quantity>2</quantity>
      </component>
      <component id='c034'>
            <name>Flange Wheel</name>
            <quantity>4</quantity>
      </component>
      <component id='c035'>
            <name>Push Bar</name>
            <quantity>1</quantity>
      </component>
      <component id='c039'>
            <name>Platform BW</name>
            <quantity>1</quantity>
      </component>
</base_module>
<lift_module id='l015'>
      <quantity>1</quantity>
      <arm_module id='a012'>
            <quantity>1</quantity>
            <component id='c002'>
                  <name>Stabilizer Type B</name>
                  <quantity>2</quantity>
            </component>
            <component id='c004'>
                  <name>Upper Lift Arm F</name>
                  <quantity>3</quantity>
            </component>
            <component id='c007'>
                  <name>Lower Lift Arm Type T</name>
                  <quantity>3</quantity>
            </component>
            <component id='c030'>
                  <name>Lift Arm Axle T</name>
                  <quantity>3</quantity>
            </component>
            <component id='c037'>
                  <name>Stabilizer Type K</name>
                  <quantity>2</quantity>
            </component>
      </arm_module>
      <power_module id='h011'>
            <quantity>1</quantity>
            <component id='c010'>
                  <name>Pump M</name>
                  <quantity>1</quantity>
            </component>
```

```
                  <component id='c012'>
                        <name>Motor-Small</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c015'>
                        <name>Hydraulic Cylinder M5</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c016'>
                        <name>Hydraulic Reservoir</name>
                        <quantity>1</quantity>
                  </component>
                  <component id='c036'>
                        <name>DC power unit</name>
                        <quantity>1</quantity>
                  </component>
            </power_module>
      </lift_module>
</product>
<product id='p034'>
      <name>Product No. 34</name>
      <inventory>155</inventory>
      <unitprice>1000</unitprice>
      <top_module id='t002'>
            <quantity>1</quantity>
            <component id='c019'>
                  <name>Platform TM</name>
                  <quantity>1</quantity>
            </component>
            <component id='c025'>
                  <name>Ball transfer top</name>
                  <quantity>1</quantity>
            </component>
      </top_module>
      <base_module id='b013'>
            <quantity>1</quantity>
            <component id='c020'>
                  <name>Platform BM</name>
                  <quantity>1</quantity>
            </component>
            <component id='c024'>
                  <name>Fork Pocket</name>
                  <quantity>1</quantity>
            </component>
      </base_module>
      <lift_module id='l019'>
            <quantity>1</quantity>
            <arm_module id='a014'>
                  <quantity>1</quantity>
                  <component id='c001'>
                        <name>Stabilizer Type A</name>
                        <quantity>4</quantity>
                  </component>
                  <component id='c003'>
```

```xml
                <name>Upper Lift Arm A</name>
                <quantity>4</quantity>
            </component>
            <component id='c006'>
                <name>Lower Lift Arm Type I</name>
                <quantity>4</quantity>
            </component>
            <component id='c030'>
                <name>Lift Arm Axle T</name>
                <quantity>4</quantity>
            </component>
        </arm_module>
        <power_module id='h009'>
            <quantity>1</quantity>
            <component id='c009'>
                <name>Pump S</name>
                <quantity>1</quantity>
            </component>
            <component id='c011'>
                <name>Motor-Large</name>
                <quantity>1</quantity>
            </component>
            <component id='c013'>
                <name>Hydraulic Cylinder M3</name>
                <quantity>2</quantity>
            </component>
            <component id='c016'>
                <name>Hydraulic Reservoir</name>
                <quantity>1</quantity>
            </component>
            <component id='c036'>
                <name>DC power unit</name>
                <quantity>1</quantity>
            </component>
        </power_module>
    </lift_module>
</product>
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    <unitprice>300</unitprice>
    <top_module id='t003'>
        <quantity>1</quantity>
        <component id='c019'>
            <name>Platform TM</name>
            <quantity>1</quantity>
        </component>
        <component id='c022'>
            <name>Turn table</name>
            <quantity>1</quantity>
        </component>
    </top_module>
    <base_module id='b012'>
        <quantity>1</quantity>
```

```
        <component id='c034'>
            <name>Flange Wheel</name>
            <quantity>4</quantity>
        </component>
        <component id='c035'>
            <name>Push Bar</name>
            <quantity>1</quantity>
        </component>
        <component id='c040'>
            <name>Platform BN</name>
            <quantity>2</quantity>
        </component>
    </base_module>
    <lift_module id='l017'>
        <quantity>1</quantity>
        <arm_module id='a011'>
            <quantity>1</quantity>
            <component id='c002'>
                <name>Stabilizer Type B</name>
                <quantity>4</quantity>
            </component>
            <component id='c005'>
                <name>Upper Lift Arm W</name>
                <quantity>2</quantity>
            </component>
            <component id='c008'>
                <name>Lower Lift Arm Type M</name>
                <quantity>2</quantity>
            </component>
            <component id='c031'>
                <name>Lift Arm Axle M</name>
                <quantity>2</quantity>
            </component>
        </arm_module>
        <power_module id='h014'>
            <quantity>1</quantity>
            <component id='c009'>
                <name>Pump S</name>
                <quantity>1</quantity>
            </component>
            <component id='c011'>
                <name>Motor-Large</name>
                <quantity>1</quantity>
            </component>
            <component id='c014'>
                <name>Hydraulic Cylinder M4</name>
                <quantity>4</quantity>
            </component>
            <component id='c017'>
                <name>Hydraulic Reservoir II</name>
                <quantity>1</quantity>
            </component>
        </power_module>
    </lift_module>
```

```
      </product>
</product_information>
```

APPENDIX E

WEB-BASED PROGRAM FOR FUZZY-ART NEURAL NETWORK

(PHP SCRIPTING LANGUAGE)

E1. User interface page source code (Input.php):

```
<html><head><title>Query Making</title></head>

<body>

<center><h3>New Design Query</h3>

<form method="post" action="query.php">

<table cellspacing=10 cellpadding=1 border=1><tr valign=top><td>

<table  cellspacing=3 cellpadding=3 border=1>

<?

$db_name = "liftdb2";

$connection = @mysql_connect("localhost","vorapoch","angkasith")

      or die(mysql_error());

$db = @mysql_select_db($db_name, $connection)

      or die(mysql_error());

echo "<tr><td>";

echo "Top Module Selection</td><td>Part

No.</td><td>Quantity</td></tr>";

$sql = "select c.cid,cname from tcomponent c where cmodule='t'";

$result =@mysql_query($sql,$connection)

      or die(mysql_error());

$ct=0;

while ($row=mysql_fetch_array($result)){

      $cid=$row['cid'];

      $cat=$row['cname'];

      $ct++;

      echo "<tr><td><a href='showcom.php?com=$cid' target='_blank'>";

        echo $cat;

        echo "</a></td><td>";
```

```
        echo $cid;
        echo "</td><td>     <input type='text'
name='$cid' size=2 maxlength=2 value='0'></td></tr>";
    }
echo "</table></td><td><table cellspacing=3 cellpadding=3
border=1><tr><td>";
echo "Base Module Selection</td><td>Part
No.</td><td>Quantity</td></tr>";
$sql = "select c.cid,cname from tcomponent c where cmodule='b'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
$ct=0;
while ($row=mysql_fetch_array($result)){
      $cid=$row['cid'];
      $cat=$row['cname'];
      $ct++;
      echo "<tr><td><a href='showcom.php?com=$cid' target='_blank'>";
        echo $cat;
        echo "</a></td><td>";
        echo $cid;
        echo "</td><td>     <input type='text'
name='$cid' size=2 maxlength=2 value='0'></td></tr>";
    }
echo "</table></td></tr><tr valign=top><td><table cellspacing=3
cellpadding=3 border=1><tr><tr><td>";
echo "Arm Module Selection</td><td>Part
No.</td><td>Quantity</td></tr>";
```

```
$sql = "select c.cid,cname from tcomponent c where cmodule='a'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
$ct=0;
while ($row=mysql_fetch_array($result)){
      $cid=$row['cid'];
      $cat=$row['cname'];
      $ct++;
      echo "<tr><td><a href='showcom.php?com=$cid' target='_blank'>";
        echo $cat;
        echo "</a></td><td>";
        echo $cid;
        echo "</td><td>     <input type='text'
name='$cid' size=2 maxlength=2 value='0'></td></tr>";
    }
echo "</table></td><td><table cellspacing=3 cellpadding=3
border=1><tr><td>";
echo "Power Module Selection</td><td>Part
No.</td><td>Quantity</td></tr>";
$sql = "select c.cid,cname from tcomponent c where cmodule='h'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
$ct=0;
while ($row=mysql_fetch_array($result)){
      $cid=$row['cid'];
      $cat=$row['cname'];
      $ct++;
```

```
      echo "<tr><td><a href='showcom.php?com=$cid' target='_blank'>";
        echo $cat;
        echo "</a></td><td>";
        echo $cid;
        echo "</td><td>      <input
type='text' name='$cid' size=2 maxlength=2 value='0'></td></tr>";
    }
?>
</tr></table></td></tr>
<tr align=center><td>Similarity Level
 <select name="vp">
  <option>(Similarity Level)</option>
  <option value="0.1">0.1</option>
  <option value="0.2">0.2</option>
  <option value="0.3">0.3</option>
  <option value="0.4">0.4</option>
  <option value="0.5">0.5</option>
  <option value="0.6">0.6</option>
  <option value="0.7">0.7</option>
  <option value="0.8">0.8</option>
  <option value="0.9">0.9</option>
 </select></td>
<td >
<input type="submit" name="submit" value="Search DATABASE">
</td></tr></table></form></center></body></html>
```

E2. Query execution source code (query.php):

```
<html><head><title>Product Referenses</title></head>

<body>

<?

$db_name = "liftdb2";

$table_name = "tcomponent";

$connection = @mysql_connect("localhost","vorapoch","angkasith")

      or die(mysql_error());

$db = @mysql_select_db($db_name, $connection)

      or die(mysql_error());


$sql = "select c.* from tcomponent c";

$result =@mysql_query($sql,$connection)

      or die(mysql_error());

$cnt=0;

while ($row=mysql_fetch_array($result)){

      $cidtemp[$cnt] = $row['cid'];

      $cidxtmp[$cnt]=$row['cidx'];

      $cmtmp[$cnt]=$row['cmodule'];

      $cnametmp[$cnt]=$row['cname'];

      $cnt++;

}

// matrix size

$msize=50;

for ($i=0;$i< $msize;$i++){

      for ($j=0;$j< $msize;$j++){

            $query[$i][$j]=0;
```

```
        }
}
for ($i=0;$i<$cnt;$i++){
        $temp = $cidtemp[$i];
        if($_POST[$temp]>0){
                if($cmtmp[$i]=='t'){
                        $cidx = $cidxtmp[$i];
                        $cq = $_POST[$temp];
                        $query[$cidx+5][1]=$cq;
                        }
                if($cmtmp[$i]=='b'){
                        $cidx = $cidxtmp[$i];
                        $cq = $_POST[$temp];
                        $query[$cidx+5][2]=$cq;
                        }
                if($cmtmp[$i]=='a'){
                        $cidx = $cidxtmp[$i];
                        $cq = $_POST[$temp];
                        $query[$cidx+5][4]=$cq;
                        }
                if($cmtmp[$i]=='h'){
                        $cidx = $cidxtmp[$i];
                        $cq = $_POST[$temp];
                        $query[$cidx+5][5]=$cq;
                        }
                }
}
```

```
$query[1][0]=1;
$query[2][0]=1;
$query[3][0]=1;
$query[4][3]=1;
$query[5][3]=1;
echo "<table  cellspacing=1 cellpadding=5 border=1><tr
align=center><td>Query Components</td><td>Quantity</td></tr>";
for ($i=0;$i<$cnt;$i++){
      $temp = $cidtemp[$i];
      if($_POST[$temp]>0){
            if($cmtmp[$i]=='t'){
                  echo "<tr align=center><td>";
                  echo $cnametmp[$i];
                  echo "</td><td>";
                  $cq = $_POST[$temp];
                  echo $cq;
                  echo "</td></tr>";
                  }
            if($cmtmp[$i]=='b'){
                  echo "<tr align=center><td>";
                  echo $cnametmp[$i];
                  echo "</td><td>";
                  $cq = $_POST[$temp];
                  echo $cq;
                  echo "</td></tr>";
                  }
            if($cmtmp[$i]=='a'){
```

```
                  echo "<tr align=center><td>";
                  echo $cnametmp[$i];
                  echo "</td><td>";
                  $cq = $_POST[$temp];
                  echo $cq;
                  echo "</td></tr>";
                  }
            if($cmtmp[$i]=='h'){
                  echo "<tr align=center><td>";
                  echo $cnametmp[$i];
                  echo "</td><td>";
                  $cq = $_POST[$temp];
                  echo $cq;
                  echo "</td></tr>";
                  }
            }
}
$vplow=$_POST[vp];
// vp value from web goto fuzzyart.php
include ('fuzzyart.php');
echo "<p>There are currently $count products in database.";
?>
<form method="post" action="showoutput.php">
<table cellspacing=3 cellpadding=3>
<tr>
<td valign=top>
<p><strong>Enter Product Number</strong><br>
```

```
   <input type="text" name="prod" size=5 maxlength=5 ></p>
<p><input type="submit" name="submit" value="Display a product"></p>
</tr></td></table>
</form>
<form method="post" action="modulex.php">
<table cellspacing=3 cellpadding=3>
<tr>
<td valign=top>
<p><strong>Enter Product Number</strong><br>
<input type="text" name="prod" size=5 maxlength=5 ></p>
<p><input type="submit" name="submit" value="Display in XML Form"></p>
</tr></td></table></form></body></html>
```

E3. Retrieval mechanism source code (fuzzyart.php):

```
<?
// set values
$Sel_Binary=0;
$Sel_Scale=1;
$alfa=0.100;
$beta=1.000;
$db_name = "liftdb2";
$connection = @mysql_connect("localhost","vorapoch","angkasith")
      or die(mysql_error());
$db = @mysql_select_db($db_name, $connection)
      or die(mysql_error());
$sql = "select p.pid from tproduct p";
$result =@mysql_query($sql,$connection)
```

```
      or die(mysql_error());
$count=0;
while ($row=mysql_fetch_array($result)){
      $index[$count] = $row['pid'];
      $count++;
}
$sql = "select count(*) from tcomponent"; // count number of component
in table
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $mz = $row['count(*)'];
}
$msize =$mz+6; // 6 modules added
for ($allpro=0;$allpro < $count;$allpro++){
      $prod=$index[$allpro];
for ($i=0;$i< $msize;$i++){
      for ($j=0;$j< $msize;$j++){
            $rawdata[$i][$j]=0;
      }
}
$sql = "select pt.* from  tproduct p, tprotop pt where p.pid=pt.pid and
p.pid='$prod'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $pid = $row['pid'];
```

```
        $tid = $row['tid'];
        $tq = $row['tq'];
}
$sql = "select pb.* from tproduct p, tprobase pb where p.pid=pb.pid and
p.pid='$prod'";
$result =@mysql_query($sql,$connection)
        or die(mysql_error());
while ($row=mysql_fetch_array($result)){
        $pid = $row['pid'];
        $bid = $row['bid'];
        $bq = $row['bq'];
}
$sql = "select pl.* from tproduct p, tprolift pl where p.pid=pl.pid and
p.pid='$prod'" ;
$result =@mysql_query($sql,$connection)
        or die(mysql_error());
while ($row=mysql_fetch_array($result)){
        $pid = $row['pid'];
        $lid = $row['lid'];
        $lq = $row['lq'];
}
$sql = "select la.* from tprolift pl, tliftarm la where pl.lid=la.lid
and pl.pid='$prod'";
$result =@mysql_query($sql,$connection)
        or die(mysql_error());
while ($row=mysql_fetch_array($result)){
        $lid = $row['lid'];
```

```
      $aid = $row['aid'];
      $aq = $row['aq'];
}
$sql = "select lh.* from tprolift pl, tliftpow lh where pl.lid=lh.lid
and pl.pid='$prod'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $lid = $row['lid'];
      $hid = $row['hid'];
      $hq = $row['hq'];
}
$rawdata[1][0]=$tq;
$rawdata[2][0]=$bq;
$rawdata[3][0]=$lq;
$rawdata[4][3]=$aq;
$rawdata[5][3]=$hq;
$sql = "select pc.pid, c.*, pc.cq from  tprocom pc , tcomponent c where
pc.cid=c.cid and pc.pid='$prod'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $pid = $row['pid'];
      $cid = $row['cid'];
      $cidx = $row['cidx'];
      $cname = $row['cname'];
      $cq = $row['cq'];
```

```
        $rawdata[$cidx+5][0]=$cq;
}
$sql = "select tc.tid, c.*, tc.cq from  ttopcom tc , tcomponent c where
tc.cid=c.cid and tc.tid='$tid'" ;
$result =@mysql_query($sql,$connection)
        or die(mysql_error());
while ($row=mysql_fetch_array($result)){
        $tid = $row['tid'];
        $cid = $row['cid'];
        $cidx = $row['cidx'];
        $cname = $row['cname'];
        $cq = $row['cq'];
        $rawdata[$cidx+5][1]=$cq;
}
$sql = "select bc.bid, c.*, bc.cq from  tbasecom bc , tcomponent c
where bc.cid=c.cid and bc.bid='$bid'" ;
$result =@mysql_query($sql,$connection)
        or die(mysql_error());
while ($row=mysql_fetch_array($result)){
        $bid = $row['bid'];
        $cid = $row['cid'];
        $cidx = $row['cidx'];
        $cname = $row['cname'];
        $cq = $row['cq'];
        $rawdata[$cidx+5][2]=$cq;
}
```

```
$sql = "select lc.lid, c.*, lc.cq from  tliftcom lc , tcomponent c
where lc.cid=c.cid and lc.lid='$lid'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $lid = $row['lid'];
      $cid = $row['cid'];
      $cidx = $row['cidx'];
      $cname = $row['cname'];
      $cq = $row['cq'];
      $rawdata[$cidx+5][3]=$cq;
}
$sql = "select ac.aid, c.*, ac.cq from  tarmcom ac , tcomponent c where
ac.cid=c.cid and ac.aid='$aid'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $aid = $row['aid'];
      $cid = $row['cid'];
      $cidx = $row['cidx'];
      $cname = $row['cname'];
      $cq = $row['cq'];
      $rawdata[$cidx+5][4]=$cq;
}
$sql = "select hc.hid, c.*, hc.cq from  tpowcom hc , tcomponent c where
hc.cid=c.cid and hc.hid='$hid'" ;
$result =@mysql_query($sql,$connection)
```

```
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $hid = $row['hid'];
      $cid = $row['cid'];
      $cidx = $row['cidx'];
      $cname = $row['cname'];
      $cq = $row['cq'];
      $rawdata[$cidx+5][5]=$cq;
}
  $i2i=0;
  for ($i=0;$i< $msize;$i++){
      for ($j=0;$j< $msize;$j++){
            $data[$allpro][$i2i] = $rawdata[$i][$j];
            $i2i++;
      }
 }
}
$i2i=0;
for ($i=0;$i< $msize;$i++){
      for ($j=0;$j< $msize;$j++){
            $data[$allpro][$i2i]=$query[$i][$j];
            $i2i++;
      }
}
$m=$count+1;
$n=$i2i;
////////////////////////////
```

```
// S matrix
for($ip=0;$ip<$m;$ip++){
// square matrix
   $dimension = sqrt($n);
   $check = floor($dimension);
   if (($dimension-$check)==0){
      } else {
      echo ("This is not a square matrix <br>");
      }
      for($ia=0; $ia<$n; $ia++){
            $Aelem[$ia]=$data[$ip][$ia];
            $Belem[$ia]=$data[$ip][$ia];
            $Selem[$ia]=$data[$ip][$ia];
      }

// Start multiplication
// $limit = amount of time that matrices are multiplied
$limit=2;
for($in=0;$in<$limit;$in++){
   $idxC = 0;
   for($ix=0; $ix< $dimension; $ix++){
      for($kx=0; $kx< $dimension; $kx++) {
         $idxA = $ix * $dimension;
         $endA = $idxA + $dimension;
         $idxB = $kx;
         while ( $idxA < $endA ) {
            $Celem[$idxC] += $Aelem[$idxA] * $Belem[$idxB];
```

```
            $idxA++;
            $idxB += $dimension;
         }
         $idxC++;
      }
   }
   for($is=0; $is<$n; $is++){
      $Selem[$is] += $Celem[$is];
        }
   for($ic=0; $ic<$n; $ic++){
      $Aelem[$ic]=$Celem[$ic];
      $Celem[$ic]=0;
      }
}
// display S matrix
   for($ic=0; $ic<$n; $ic++){
       $data[$ip][$ic]=$Selem[$ic];
      }
}
// end S matrix
// generate new data
            for($i=0; $i< $m; $i++){
          for ($j=0; $j< $n; $j++){
          $new_data[$i][$j] = $data[$i][$j];
          }
        }
      if($Sel_Binary == 1){
```

```
    for($i=0; $i< $m; $i++){
       for($j=0; $j< $n; $j++){
          if ($new_data[$i][$j] > 0){
            $new_data[$i][$j] = 1.0;
          }
          else {
            $new_data[$i][$j] = 0.0;
        }
      }
  }
      }
else
{
      for($j=0; $j<$n; $j++){
         $max_feature[$j] = 0;
         $min_feature[$j] = 0;
      }
      for($i=0; $i<$m; $i++){
         for($j=0; $j<$n; $j++){
            if ($new_data[$i][$j] > $max_feature[$j]){
               $max_feature[$j] = $new_data[$i][$j];
            }
            if ($new_data[$i][$j] < $min_feature[j]){
               $min_feature[$j] = $new_data[$i][$j];
            }
         }
      }
```

```
            for($i=0; $i<$m; $i++){
               for($j=0; $j<$n; $j++){
                  $value1 = $max_feature[$j]-$min_feature[$j];
                  if ($value1 <= 0){
                     $new_data[$i][$j] = 0;
                  } else {
                     $new_data[$i][$j] = ($new_data[$i][$j]-
$min_feature[$j])/$value1;
                  }
               }
            }
        }
$vp=$vplow;
      // initialize weights
      for ($i=0;$i<$n;$i++){
          for ($j=0;$j<$m;$j++){
          $LTM[$i][$j] = 1.0;
          }
      }
      if ($vp < 0.001){
            $vp=0.001;
      }
      if ($vp > 0.999){
            $vp=0.999;
      }
      for($i=0;$i<$m-1;$i++){
            for($j=0;$j<$n;$j++){
```

```
            $pattern[$j]=$new_data[$i][$j];
      }
// compute matching score
for ($x1=0;$x1<$m;$x1++){
      $up_sum=0;
      $bottom_sum=0;
    for ($y=0;$y<$n;$y++){
      if($pattern[$y]>$LTM[$y][$x1]){
          $up_sum = $up_sum + $LTM[$y][$x1];
      } else {
          $up_sum = $up_sum + $pattern[$y];
      }
      $bottom_sum = $bottom_sum + $LTM[$y][$x1];
    }
    $match_score[$x1] = $up_sum / ($alfa + $bottom_sum);
}
for($bk=0;$bk<3;$bk++){
// find max
for ($x2=0,$jmax=0; $x2 < $m; $x2++){
    if ($match_score[$x2] > $match_score[$jmax]){
      $jmax = $x2;
    }
}
// return jmax value
//vigilance
for ($i2=0,$x3=0.0; $i2<$n; $i2++){
    $x3 = $x3 + $pattern[$i2];
```

```
        }
        for ($i2=0,$t=0.0; $i2<$n; $i2++){
            if($pattern[$i2] > $LTM[$i2][$jmax]){
                $t = $t + $LTM[$i2][$jmax];
            }   else{
                $t = $t + $pattern[$i2];
            }
        }
        $vigilance = ($t/$x3);
        if($vigilance >= $vp){
        for ($i3=0; $i3<$n; $i3++){
            if ($pattern[$i3] > $LTM[$i3][$jmax]){
                $LTM[$i3][$jmax] = $beta*$LTM[$i3][$jmax] + (1-
$beta)*$LTM[$i3][$jmax];
            }   else {
                $LTM[$i3][$jmax] = $beta*$pattern[$i3] + (1-
$beta)*$LTM[$i3][$jmax];
            }
        }
                          $cluster_number[$i]=$jmax;
                          $bk=99;
                    } else {
                          $match_score[$jmax]= -1.0;
                          $bk--;
                    }
              }
        }
```

```
// print class
        $m2=$m-1;
      for($j2=0,$max_cluster=0; $j2 < $m2; $j2++){
          if($cluster_number[$j2] > $max_cluster){
              $max_cluster = $cluster_number[$j2];
      }
}
      $numberofcluster=$max_cluster+1;
      echo "<table cellspacing=2 cellpadding=10 border=1><tr
align=center><td>";
        printf( "Number of Product Groups : $numberofcluster <br>");
        echo "</td><td>Vigilance Parameter: $vp</td></tr>";
        for ($k=0; $k < $max_cluster+1; $k++){
            $clusterno=$k+1;
          printf( "<tr ><td align=center>Product group no. $clusterno
\t</td>");
          echo "<td>";
          for($j2=0; $j2<$m2; $j2++) {
              if ($cluster_number[$j2] == $k){
                  printf("   <a
href='show.php?prod=$index[$j2]'
target='_blank'>$index[$j2]</a>  ");
              }
          }printf("</td></tr>");
      }
      printf("<br>");
///////////////////////////////////////////////
```

```
// Query Pattern Here
      for($j=0;$j<$n;$j++){
            $pattern[$j]=$new_data[$m-1][$j];
      }
// compute matching score
      for ($x1=0;$x1<$m;$x1++){
            $up_sum=0;
            $bottom_sum=0;
          for ($y=0;$y<$n;$y++){
            if($pattern[$y]>$LTM[$y][$x1]){
                $up_sum = $up_sum + $LTM[$y][$x1];
            } else {
                $up_sum = $up_sum + $pattern[$y];
            }
            $bottom_sum = $bottom_sum + $LTM[$y][$x1];
          }
          $match_score[$x1] = $up_sum / ($alfa + $bottom_sum);
      }
      echo "<table cellspacing=2 cellpadding=10 border=1>";
      for($bk2=0;$bk2<7;$bk2++){
            // find max
      for ($x2=0,$jmax=0; $x2 < $m; $x2++){
          if ($match_score[$x2] > $match_score[$jmax]){
            $jmax = $x2;
          }
      }
      // return jmax value
```

```
        if($jmax > $max_cluster){
                    $bk2=99;
        } else {
        //vigilance
        for ($i2=0,$x3=0.0; $i2<$n; $i2++){
            $x3 = $x3 + $pattern[$i2];
        }
        for ($i2=0,$t=0.0; $i2<$n; $i2++){
            if($pattern[$i2] > $LTM[$i2][$jmax]){
                $t = $t + $LTM[$i2][$jmax];
            }   else{
                $t = $t + $pattern[$i2];
            }
        }
        $vigilance = ($t/$x3);
              if($vigilance >= $vp){
                    printf("<tr align=center><td>Suggested similar
products are in cluster no. %d</td></tr>",$jmax+1);
                    $bk2++;
              } else {
                    $bk2++;
              }
              $match_score[$jmax]= -1.0;
        }
        }echo "</table>";
?>
```

E4. XML document converting source code (modulex.php)

```
<?php
header("Content-type: text/xml");
$db_name = "liftdb2";
$connection = @mysql_connect("localhost","vorapoch","angkasith")
      or die(mysql_error());
$db = @mysql_select_db($db_name, $connection)
      or die(mysql_error());
$xml_output = "<?xml version=\"1.0\"?>\n";
$xml_output .= "<product_information>\n";
$prodtemp=$_POST[prod];
$prod=$prodtemp;
$file= fopen("xml/".$prod.".xml", "w");
/////////////////
// Product     //
/////////////////
$sql = "select p.* from  tproduct p where p.pid='$prod'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $xml_output .= "\t<product id='".$row['pid']."'>\n";
      $xml_output .= "\t\t<name>" . $row['pname'] . "</name>\n";
      $xml_output .= "\t\t<inventory>" . $row['pstock'] .
"</inventory>\n";
      $xml_output .= "\t\t<unitprice>" . $row['pprice'] .
"</unitprice>\n";
      }
```

```
$sql = "select pc.pid, c.*, pc.cq from  tprocom pc , tcomponent c where
pc.cid=c.cid and pc.pid='$prod'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $xml_output .= "\t\t<component id='".$row['cid']."'>\n";
      $xml_output .= "\t\t\t<name>" . $row['cname'] . "</name>\n";
      $xml_output .= "\t\t\t<quantity>" . $row['cq'] . "</quantity>\n";
      $xml_output .= "\t\t</component>\n";
      }
////////////////
// Top module //
////////////////
$sql = "select pt.* from  tproduct p, tprotop pt where p.pid=pt.pid and
p.pid='$prod'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $tid=$row['tid'];
      $xml_output .= "\t\t<top_module id='".$row['tid']."'>\n";
      $xml_output .= "\t\t\t<quantity>" . $row['tq'] . "</quantity>\n";
      }
$sql = "select tc.tid, c.*, tc.cq from  ttopcom tc , tcomponent c where
tc.cid=c.cid and tc.tid='$tid'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
```

```
	$xml_output .= "\t\t\t<component id='".$row['cid']."'>\n";
	$xml_output .= "\t\t\t\t<name>" . $row['cname'] . "</name>\n";
	$xml_output .= "\t\t\t\t<quantity>" . $row['cq'] .
"</quantity>\n";
	$xml_output .= "\t\t\t</component>\n";
	}
	$xml_output .= "\t\t</top_module>\n";
/////////////////
// base module //
/////////////////
$sql = "select pb.* from tproduct p, tprobase pb where p.pid=pb.pid and
p.pid='$prod'";
$result =@mysql_query($sql,$connection)
	or die(mysql_error());
while ($row=mysql_fetch_array($result)){
	$bid=$row['bid'];
	$xml_output .= "\t\t<base_module id='".$row['bid']."'>\n";
	$xml_output .= "\t\t\t<quantity>" . $row['bq'] . "</quantity>\n";
	}
$sql = "select bc.bid, c.*, bc.cq from  tbasecom bc , tcomponent c
where bc.cid=c.cid and bc.bid='$bid'" ;
$result =@mysql_query($sql,$connection)
	or die(mysql_error());
while ($row=mysql_fetch_array($result)){
	$xml_output .= "\t\t\t<component id='".$row['cid']."'>\n";
	$xml_output .= "\t\t\t\t<name>" . $row['cname'] . "</name>\n";
```

```
	$xml_output .= "\t\t\t\t<quantity>" . $row['cq'] .
"</quantity>\n";
	$xml_output .= "\t\t\t</component>\n";
	}
	$xml_output .= "\t\t</base_module>\n";
/////////////////
// lift module //
/////////////////
$sql = "select pl.* from tproduct p, tprolift pl where p.pid=pl.pid and
p.pid='$prod'";
$result =@mysql_query($sql,$connection)
	or die(mysql_error());
while ($row=mysql_fetch_array($result)){
	$lid=$row['lid'];
	$xml_output .= "\t\t<lift_module id='".$row['lid']."'>\n";
	$xml_output .= "\t\t\t<quantity>" . $row['lq'] . "</quantity>\n";
	}
$sql = "select lc.lid, c.*, lc.cq from  tliftcom lc , tcomponent c
where lc.cid=c.cid and lc.lid='$lid'" ;
$result =@mysql_query($sql,$connection)
	or die(mysql_error());
while ($row=mysql_fetch_array($result)){
	$xml_output .= "\t\t\t<component id='".$row['cid']."'>\n";
	$xml_output .= "\t\t\t\t<name>" . $row['cname'] . "</name>\n";
	$xml_output .= "\t\t\t\t<quantity>" . $row['cq'] .
"</quantity>\n";
	$xml_output .= "\t\t\t</component>\n";
```

```
      }
////////////////
// arm module //
////////////////
$sql = "select la.* from tprolift pl, tliftarm la where pl.lid=la.lid
and pl.pid='$prod'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $aid=$row['aid'];
      $xml_output .= "\t\t\t<arm_module id='".$row['aid']."'>\n";
      $xml_output .= "\t\t\t\t<quantity>" . $row['aq'] .
"</quantity>\n";
      }
$sql = "select ac.aid, c.*, ac.cq from  tarmcom ac , tcomponent c where
ac.cid=c.cid and ac.aid='$aid'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $xml_output .= "\t\t\t\t<component id='".$row['cid']."'>\n";
      $xml_output .= "\t\t\t\t\t<name>" . $row['cname'] . "</name>\n";
      $xml_output .= "\t\t\t\t\t<quantity>" . $row['cq'] .
"</quantity>\n";
      $xml_output .= "\t\t\t\t</component>\n";
      }
      $xml_output .= "\t\t\t</arm_module>\n";
//////////////////
```

```
// power module //
//////////////////
$sql = "select lh.* from tprolift pl, tliftpow lh where pl.lid=lh.lid
and pl.pid='$prod'";
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $hid=$row['hid'];
      $xml_output .= "\t\t\t<power_module id='".$row['hid']."'>\n";
      $xml_output .= "\t\t\t\t<quantity>" . $row['hq'] .
"</quantity>\n";
      }
$sql = "select hc.hid, c.*, hc.cq from  tpowcom hc , tcomponent c where
hc.cid=c.cid and hc.hid='$hid'" ;
$result =@mysql_query($sql,$connection)
      or die(mysql_error());
while ($row=mysql_fetch_array($result)){
      $xml_output .= "\t\t\t\t<component id='".$row['cid']."'>\n";
      $xml_output .= "\t\t\t\t\t<name>" . $row['cname'] . "</name>\n";
      $xml_output .= "\t\t\t\t\t<quantity>" . $row['cq'] .
"</quantity>\n";
      $xml_output .= "\t\t\t\t</component>\n";
      }
$xml_output .= "\t\t\t</power_module>\n";
$xml_output .= "\t\t</lift_module>\n";
$xml_output .= "\t</product>\n";
$xml_output .= "</product_information>";
```

```
echo $xml_output;

fwrite($file, $xml_output);

fclose($file);

?>
```

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