CUSTOMER-LED CONCEPTUAL DESIGN SYSTEM

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy, is entirely my own work, I have exercised reasonable care to ensure the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Acknowledgements

This thesis is dedicated to mycrown (my wife) and my beautiful daughters- Ebunoluwa & Oluwademilade

Abstract

This research work is aimed at carrying out a feasibility study for the design of a Customer-Led Design (CLD) system that will allow individuals or users with little or no technical know-how of engineering design but with an idea of what they want to bring the idea into reality through the customer driven-design system. Customer-Led design (CLD) is a customer co-design process of products and services which meet the needs of each individual customer/user with regard to certain product features

and all operations are performed within a fixed solution space, characterized by stable but still flexible and responsive processes.

Outstanding developments have been recorded in the Customer driven design systems in some areas such as shoes, kitchen and computers industries that have allowed customers to create their own product from the pre-defined catalogue of options made available by the manufacturers or designers. However, some customers might have an idea of a product which may not be in the pre-defined database of the manufacturer or designer and which the customer wants to have, especially mechanically oriented products and this is what has led to undertaking this research work.

The activities that were carried out to achieve the objective of the project to date involved developing a hybrid (hierarchical and chain-type) classification system to group the products into classes and sub-classes using attributes such as applications, external and internal motions, shape, weight and material types etc.. Also, each of these classes was also grouped hierarchically linking one section of classification to another in a chain type that will eventually lead the customers to their intended product. Other aspects were the configuration of products which makes it possible to add and/or change functionalities of a core product by suggesting similar products if the requested product is not found, a coding system for mechanical designs and applying it to each product according to their position in the hierarchy, the use of a database to store and retrieve information about the products and the modification of the selected similar product to suit the user's/customer's desired product.

While similar designs may have been implemented in some industries, this offers the customers more flexibility in designing their own products with varieties of products from different family of products which are not inherent in the other systems.

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Glossary of Acronyms

ACRONYM	DEFINITION
PCS	Product Chain System
CLD	Customer-Led Design
CDD	Customer Driven Design
ANN	Artificial Neural Network
MC	Mass Customisation
GT	Group Technology
AHP	Analytic Hierarchy Process
DOF	Degrees of Freedom
MDCS	Mechanical Design Code System
PF	Product Family
APP	Application
WF	Weight Factor
SI	Similarity Index
NN	Neural Network
S/A	Sub-Assembly
SIV	Similarity Index Value

CHAPTER ONE

INTRODUCTION

1.1 Background

It's a fact of life. Customer demand is increasingly stretching manufacturing capability to the limit [1]. In an environment of mass customisation, the level of customer involvement and latitude afforded to the customer is necessarily limited; even the products family on offer is limited as well. This is largely driven by the manufacturers' desire to maintain mass production-type economies and the desire to maintain control [2] and as a result, the flexibility that ought to come along in a co-design setting with the customer/user designing their own products with varieties of products from different family of products has been greatly affected. Consumers are becoming increasingly insistent on having a say in the design of products and looking for an avenue to bring their ideas to reality and this is where Customer-Led Design (CLD) comes to help. The ability of customers to participate in the design of the products and services they purchase has permeated nearly every segment of consumption and the customer having a voice and hand in the design of his/her product is one of the most powerful, fulfilling intangibles of the purchase experience.

1.2 Aim of the Project

This research work is aimed at developing a Customer-Led Design (CLD) system that will allow an individual with little or no technical know-how of engineering design but with an idea of what he/she wants to bring the idea into reality through the customer driven-design system. Customer-Led Design (CLD) is a **customer co-design process** of products and services which meet the **needs of each individual customer/user with regard to** *certain product features* and all operations are performed within a **fixed solution space**, characterized by stable but still flexible and responsive processes [3]

Customers are integrated into the creation of the design by defining, configuring, matching, or modifying an individual product - mainly mechanical related products.

This is done by the application of a hybrid (combined hierarchical and chain-type) classification system to group the products into classes and sub-classes using attributes such as Applications, Motions, Energy Source, Power Rate, Maximum Dimension, Weight of the Product, Product Shape, and Material from which the product is made of; the Configuration of products which make it possible to add and/or change functionalities of a core product by suggesting similar products if the requested product is not found; a coding system for mechanical designs and applying it to each product according to their position in the hierarchy; and the use of a database to store and retrieve information about the products [4].

1.3 Objectives of the Research

The development of Customer-Led Design Systems (CLD) arises from the need to develop effective and efficient   systems that will enable the customer/user with little or no technical knowledge the flexibility, creativity and influence they desire in bringing their ideal product into reality where these were not part of similar systems and also to allow them to select from different family of products in order to build their own product. Established Group Technology (GT) concepts in the area of classification, coding, search and retrieval of similar designs were modified to suit the purpose of the CLD system used. The GT structure has been employed to classify the mechanically oriented products into different applications, and each product was coded using a code system for mechanical design. Having selected a product from various applications in combination with other attributes, the customers build their own individual product and if the initial configuration does not yield any product code from the product database, two methods have been developed to suggest a similar product codes from the product database.

The developed system is to deal with conceptual design of products with the guidance of the customer.

1.3.1 User's Objective

The objective of the Customer-Led Design system is to allow the customer/user to design a novel product by trial-and-error experimentation and deliver immediate (simulated) feedback on the potential outcome of their design ideas. The idea is to

carry out a feasibility study in order to develop software that will allow users without a technical know-how or knowledge to practically develop/design and produce their desired products. The system should provide the following:

1. Be easy to use by a person with little or no engineering design knowledge.

2. Allow the customer/user to bring his/her product and design ideas into realisation

3. Allow the customer/user to customise his/her product through a guided or tailored interactive approach system that is responsible for providing the custom product.

1.3.2 Industrial Objective

From an industry perspective this research work is expected to contribute to the reduction in lead-time, cost and labour in re-designing of new products as this would have been carried out by the customer. This industry objective is based on the premise that such a system will adequately permit the involvement of the customer as a co-designer so that the manufacturer will not need to go through the rigour of design stage in the product development process. It will significantly improve the ability to leverage common components in a product platform with an appropriate level and implementation of customer product variety required to meet the customer expectations.

Furthermore, the research work is expected to provide some insights into how such system structure can influence some aspects of the product development process, especially the feasibility study and design stage. The anchoring of the CLD structure with established product chain attributes and methodologies is an important aspect to ensure the potential of a systematic approach to the CLD system that is built upon proven and well-founded concepts and theories. This is important in order to build confidence in the proposed design system as well as tap in and connect to existing knowledge and competence to execute development work utilising the proposed approach.

1.3.3 Scientific Objective

From a scientific point of view, this project is expected to contribute to and improve how customer integration can be effectively implemented in the customer-driven design system by the application of the proposed design theory and design methodology in order to improve customer role as a co-designer in the Customer-led Design system context described above. An important element in achieving this will be an information framework – or integrated product chain-hierarchical classification structure based on a Group Technology concept, Similarity Retrieval system, Artificial Neural Network and Customisation process.

1.4 Approach of Thesis

To meet the initial objectives of this research work, a comprehensive study was conducted on the current state of art in customer-driven design problems. To this effect, a customer-led design system was initiated and a method of effectively integrating the customer as a co-designer was formulated. Based on this study, a hybrid classification system was designed to assist the customer in bringing out the design idea and guide them in decision making as regard their products. This hybrid system is composed of various Product Chain System (PCS) attributes such as applications, motion, materials of the product, product dimension, shape etc. The purpose of the product chain system was to assist the customer in decision making by narrowing down the customer's choice to the desired product or at least to find the closest ones to it.

The research was further extended to check up how a similar product could be retrieved if the desired customer product could not be located in the database of the system and how to modify the similar product retrieved from the database to match what the customer desires. For this task, retrieval systems, Analytical Hierarchy Process (Weight Factor), Similarity Coefficient and Index were studied. By modifying these theories, a new product similarity retrieval method was developed.

1.5 Tasks to be performed

In order to actualise the objective of the project, there were tasks that needed to be carried out. These tasks are broken down into various chapters and a description of each chapter is given below.

Chapter One: Introduction- this presents a brief introduction of the research system and the components that have been used to carry out this project, the background of the work, the research aim and objectives, approach adopted for the research, and tasks to be performed to achieve the research aim.

Chapter Two: Review of Literature - in this chapter a comprehensive literature survey of existing concepts that gave way to an idea of customer-led design is given and consists of four sections:

- The first section provides an overview of the customisation world

- The second section provides an overview of group technology- classification and product coding systems

- The third section presents a synopsis on retrieval systems, and

- The fourth section provides a narrative on artificial neural networks.

Chapter Three: The Customer-led Design System Approach - this chapter describes the system development phases for attributes and the overview of the CLD system. It explains the stages involved in the Product Chain System. It also explains the usage of mechanical coding systems and the role of databases in the customer-led design system.

Chapter Four: Architecture Representation and Framework for the Design of the CLD System - in this chapter, the intended principle of operation of the CLD system is described and also some of the structures that are essential for the development system.

Chapter Five: Product Selection and Modification - this chapter describes how the similar products generated by the system are modified. It explains the tasks and steps taken both on the user interface and behind the scene (that is, what happens internally when a task or step is being initiated by the user/customer on the user interface).

Chapter Six: Conclusion and Future Work - This chapter provides the main results achieved in the research so far. It also gives insight on further work to be done based on the present study.

CHAPTER TWO
REVIEW OF LITERATURE

2.1 Introduction

As stated in the previous chapter, the objective of this work is to carry out a feasibility study and develop a methodology that will allow the customer/user to design a novel product by trial-and-error experimentation and deliver immediate (simulated) feedback on the potential outcome of their design ideas. The idea is to develop software that will allow users without a technical know-how or knowledge to practically develop/design and produce their desired products. The methodology includes Product Customisation Process, Group Technology, Design Retrieval System, and Artificial Neural Network. In this chapter, the author provides detailed explanation of what is involved in the methodology and relevant works of other researchers.

2.2 Customisation of Products

Customisation has come of age since its conception by Stan Davies and further development in the early 1990s by Joseph Pine [5]. The idea was coined or adopted from the mass production concept - an approach based on producing and selling standard mass produced items, exploiting economies of scale to achieve prices that everyone could afford - this in turn was derived from the manufacturing classification system [6]. Mass customisation (MC) is defined as the customisation of individual products and services at mass production prices [7]. That is, meeting each customer's individual need exactly, but at costs comparable to those of standard mass produced goods [8].

The demand for individualised products and services is on the increase and mass customisation strives to produce customised products and services on a mass scale with the same levels of responsiveness, quality, efficiency, and costs that are typical of mass production [9] but with little flexibility or constraint that has restricted the involvement of the customer as a co-designer. R. Duray and G.W. Milligan [10]

categorised mass customisation based on external involvement of the customer in design, fabrication, assembly or delivery stages of the manufacturing process of the product, all with constraint on the part of customer involvement. In an attempt to satisfy the individualistic taste of the customer based on the product order, a method was adopted to separate products into categories such as Made-to-Stock (MTS), Assemble-to-Order (ATO), Made-to-Order (MTO), and Engineer-to-Order (ETO) [11] and all of these are examples of Customer-Driven "Manipulation", which is defined as the customer/user's ability to directly influence or manipulate a product's aesthetic, functional or dimensional characteristics [1].

Although many manufacturing firms have put MC into practice such as Dell (computer industry), Adidas Salomon (footwear industry) [12] and virtual kitchens (kitchen and cabinet industry) [13], not all the products are mechanically oriented and the degree of customer involvement is limited by pre-defined features that only allow the customer to select from the options they have made available. If the options are not satisfactory to the customer then the customer is left with no further alternatives because of the manufacturer's desire to maintain control [2]. Another aspect of limitation imposed on customers is in the type of attributes over which customers may wish to make choice, for instance in dimensions, shape, functionality, material, aesthetic aspects such as colour, styling, and finish. In order to incorporate the customer fully into the design process, Z. Siddique and J.A. Ninan [14], [15] designed a web-based framework to provide customisable products by integrating the customer into the design process. Simpson et al. [16] developed a web-based customisation system for refiner plates for pulp and paper processing. Flores et al. [17] presented a similar web-based system for customisation based on parametric modifications, for coated steel belt sheaves. Zha and Lu [18] developed a web-based knowledge system to support product family design for a power supply product family. Saxon and Beaulieu [19] developed a web based engineering system, which can perform automated FEA of stabilizer bars. These existing customisation systems or frameworks assume product configuration to be fixed and are used to scale the product. Also, these works would have been perfect models but due to constraints in the configurations the customer involvement is still restricted and the systems do not entail products varieties.

There is therefore a need for a system which will allow the customer or individual with little or no technical knowledge in engineering design to design their own product. And this system, Customer-Led Design (CLD), gives more flexibility to the customers in the design stages that satisfies the customers' individualistic demand by integrating them into the design process through defining, configuring, matching, or modifying an existing product that is mechanically oriented in nature. It also affords the customer the sense of being a co-designer without limiting his/her involvement, thereby bringing his/her idea to fruition.

CLD is a step higher from mass customisation in the sense that faced with breakdown in the conditions which enables mass customisation, that is, designing and engineering a product and its option before offering it to customers in which the customers have to select from a pre-defined catalogue of options, a realisation is growing among manufacturers that people are becoming more individualistic than ever preferring to create their own product with little interference from the manufacturer other than piloting in actualising the desired end.

2.3 Group Technology (GT)

Group Technology was introduced by Frederick Taylor in 1919 as a way to improve productivity and in 1958, Mitrofanov (a Russian engineer), formalized this concept in his book, "The Science Principle of Group Technology". Ever since, GT has become a very important tool in manufacturing and production systems. It is the oldest and most famous engineering approach for designs classification [20], [21]. Hyer and Wemmerlov described GT as "a philosophy that implies the notion of recognising and exploiting similarities by performing like activities together, standardising similar tasks and efficiently storing and retrieving information about recurring problems" [22]. Others like Tiecholz and Orr [23], and Allen [24] both agreed that GT integrates classification theory and practice in an industrial activity, applied in the design process to reduce product proliferation; and in manufacturing to improve productivity, throughput, quality and profitability. Vishwanath R et al [25] defined GT code as a string of alphanumeric characters that represent important design and manufacturing related attributes. Drawing from the various authors' contribution to GT, one can conclude that GT is a manufacturing philosophy that seeks to improve productivity by grouping parts and products with similar

characteristics into families and forming production cells with a group of dissimilar machines and processes [26]. The impacts of GT on the production process among other things are - quicker design changes, improved customer service and building customer relationship through classification. The benefits of this technique are most relevant to agile manufacturing in the area of design retrieval, part classification, variant process planning, design standardisation, and in design and manufacturability evaluation. GT can be implemented through the following techniques - classification system, coding system and retrieval system. All of these were used for classifying and coding of product parts which work hand-in-hand and retrieving of engineering design parts.

Because of its high effectiveness, the GT technique was adapted for use in the development of the classification, product coding and retrieval system for this research work and some modifications were carried out in order for it to be used in the CLD system for the consumer products family that are mechanically oriented.

2.3.1 Classification System

This is the grouping of entities that share common characteristics into a class for which uniform conditions hold [27]. It is a procedure that can be used to separate a large group of objects into different sub-groups [28]. Classification systems have been widely used in many industries and organisations over the years. Its usefulness cannot be overemphasised because most tasks performed in any system can be categorised into a smaller number of sets where each set has tasks that are very similar to each other. Its applications cut across every sector that is in existence. For instance, organisations make use of it in structuring organisational charts and products, while its application in the manufacturing sector helps in grouping parts into their families and to schedule production, thereby reducing design repetition and manufacturing lead time. It has also been extensively used alongside the coding system in the customer-driven design of many products such as footwear and computers. One of the reasons why we engage in classification is because most tasks performed in any system can be categorised into a smaller number of classes/groups, where each class/group has tasks that are very similar to each other. Classification provides the designer an important resource for selecting various parts of a product during the initial design phase. It expands the scope and utility of GT part coding and

makes it more sensitive. Thus the benefits which accrue from this classification include - providing a design database, significant reduction in design time and offer, providing innovative design solutions, allowing maximum design freedom, avoiding design duplication and encouraging standards to develop [29].

Although classification systems have been widely used in the manufacturing sectors for the purpose of grouping mechanical parts, it has not been suitably applied in grouping of the real product itself due to the complexity it entails. It can only be applied to one item at a time. The clear example of this can be seen in the car manufacturing industry where the grouping of model and data for the car cannot be classified hierarchically at the same time [26]. On the other hand, the concept of hierarchical classification has really worked well in classification systems and was therefore taken as the basis of the hybrid system of classification in this research work.

2.3.2 Coding System

A Coding system can be said to be the assigning of a symbol or a numerical description to represent information [30]. This aspect of GT has also come of age in its application to design manufacturing and is mainly used together with classification systems. Since the late 1940's, Coding systems have been used in manufacturing applications and became more popular in Europe during the following decades as GT interest grew more. A great number of systems have been developed. Knight and Gallagher [31] described 20 codes almost 30 years ago, although only quite few have gained widespread acceptance. The MICLASS [32], Opitz [33] and Brisch [34] systems are probably the best known and all of these have been in existence for many years. The drive behind their development was either related to the need to place a boundary on the growth of variety in a company's parts range or, in the case of the GT applications, to identify the families of similar parts [35]. A coding system depends on the application of the coding scheme such as coding for design retrieval with relevant features - shape, materials, size, and irrelevant feature - tolerance. The other coding scheme is coding for process planning with relevant features - tolerances, machinability, processes, and machine tool requirement [36]. The good thing about the coding scheme is that it gave the author an insight that brought about the hybrid type of classification system. For instance, the coding for

design retrieval relevant features was used to develop the Product Chain system for the product chain structure of the CLD system.

2.3.2.1 Types of Coding System

The types of coding system are pertinent to the development of the hybrid (chain-hierarchy type of classification) employed for this research and review of the relevant literature is of utmost importance for the understanding of the design of the CLD System. The coding system is of three types, namely:

1. **Hierarchical Structure or Monocodes**: in this kind of coding systems, each digit in the code stands for a feature or sub-group. The first digit represents an entire group; the next digit represents a sub-group of the feature and so on depending on the number of hierarchy level involved. That is, each code number is qualified by the preceding characters [37].

- Advantage: (*i*) it can represent large amount of information with few code positions, and (*ii)* it permits the usage of parts of the code for information at different level of the structure.

- Disadvantage: (*i*) not easy to modify and difficult to develop, and (*ii*) different sub-groups may have different levels of sub-groups thereby leading to blank codes in some positions.

2. **Chain-type or Polycode**: In this type, each symbol or digit interpretation is independent of the previous symbol/digit. That is, the value of any given digit within the code has no bearing to the other digits in the structure.

- Advantage: it's easy to construct and modify.

- Disadvantage: (*i*) it's not as detailed as hierarchical structures, and (*ii*) it is more labour intensive when comparison of coded parts are to be carried out.

3. **Hybrid Code Structure**: this is a mixture of chain and hierarchical code structures. This type of code structure captures the essential information about a part shape since it uses hierarchical structure where it is applicable (in the structure) and chain-type for the other digits. This type has found practical usefulness in the commercial arena because it exploits the advantage of both systems.

2.3.2.2 Widely Used Coding Systems

As was said early on in the section above, 20 codes were described by Gallagher and only few have gained widespread acceptance. The codes that have gained acceptance are widely used for mechanical parts coding. They include: KK-3, MICLASS [38], DCLASS [39], VUOSO PRAHA and OPITZ CODE [33]. Although the format and coding classification of these codes are different, with the exemption of Vuoso-Praha, they all summarise information on six basic part characteristics: (i) Main Shape, (ii) Form features based on the 6 main shapes, (iii) Feature position, (iv) Dimensions, (v) Tolerances, and (vi) Material.

2.3.2.2.1 KK-3 Coding System

This type was originally developed by the Japan Society for the Promotion of the Machining Industry. Basically, this is a general-purpose classification and coding system that uses 21-digits, each of which is an integer to code mainly metal-cutting and grinding components. The coding system is structured such that much more detail about a part can be represented in the coding.

2.3.2.2.2 MICLASS Coding System

The coding system is a chain-structure system developed by TNO from Holland and it uses 12 digits most of which have fixed significance to represent the component part. An additional 18 digits are available for user-specified or company-related information such as part function, piece time, etc. The MICLASS system classifies the engineering and manufacturing features of each part which consist of - main shape, position of elements, shape elements, one dimension, ratio of dimensions, an auxiliary dimension, accuracy and material. Although MICLASS can be used manually, it is available as a computer package in which the code number provides access to a component database and also application programmes for process planning, NC processing and component grouping. The structure of the system is shown in the figure below.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

Form   Dimension   Tolerance   Material
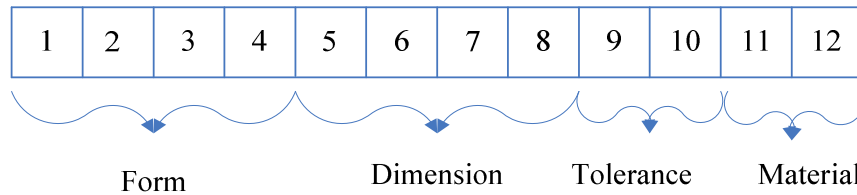
Figure 2.1: MICLASS Code Number.

The MICLASS system is so designed that one can use it to include both manufacturing and design information. It has four main parts:

a. Classification number:- parts classification based on their engineering and manufacturing characteristic are made possible

b. Database:- this holds design and manufacturing information for the whole organisation

c. Retrieval programmes:- drawings retrieval, sheets routing, manufacturing instructions, etc, are made possible by these programmes, and

d. Analysis programmes: - these are used for design standardisation, optimisation of machine tool use, and manufacturing routines.

2.3.2.2.3 MULTICLASS Coding System

This is the newest version of MICLASS and was developed by the Organisation for Industrial Research (OIR). It permits the entering of part descriptions quickly and easily in a tightly organised structure that effectively supports retrieval and analysis. The system is somewhat flexible, allowing the users to customise the classification and coding scheme to a large extent to fit their own product and application. It also permits the users to retrieve parts by keywords, features, individual characteristics, parts numbers, classification numbers, or other data.

MULTICLASS uses a hierarchical coding structure in which the next digits depend on values of the previous digits. The coding structure consists of up to 30 digits and these digits are divided into two regions; one provided by OIR and the second designed by the user to meet specific requirements. A prefix precedes the 30 digits

27

and is used to identify the type of part. The figure below shows the general structure of MULTICLASS.
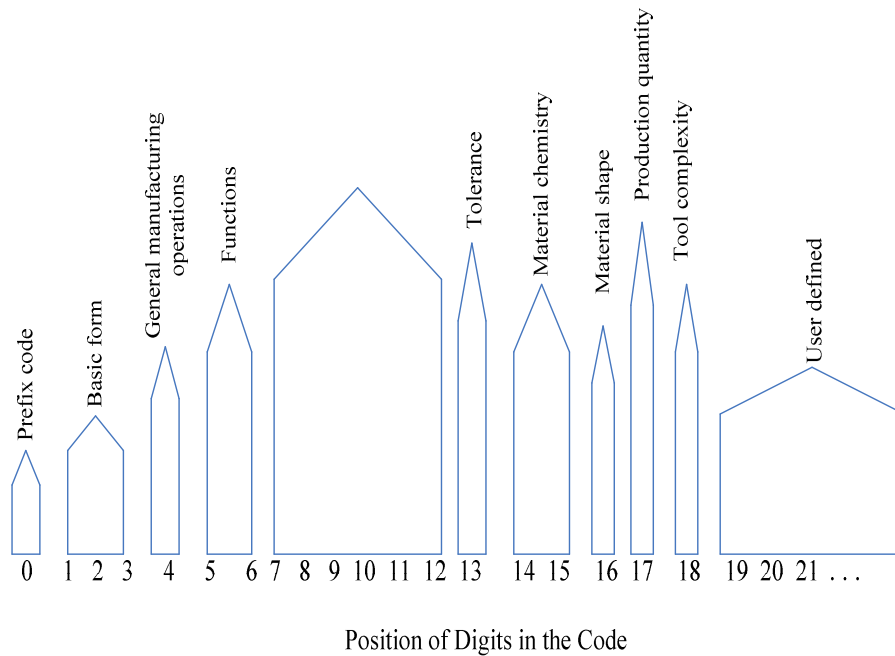
Figure 2.2: MULTICLASS Coding System.

2.3.2.2.4 DCLASS Coding System

DCLASS was developed in 1980 by D.K. Allen and P.R. Smith at Brigham Young University. This system stands for Decision CLASSification Information System. This is a computerised method to classify, store, and retrieve information efficiently and rapidly, to do calculations, and to aid in decision-making [39], [40].

At the heart of the DCLASS system are trees designed to show relationships and processes. There are five types of trees [40]:

    I.   E-Tree (mutually exclusive branching)

    II.   N-Tree (non-mutually exclusive multiple path)

    III.   C-Tree (combination of E and N Trees)

    IV.   X-Tree (computer mathematical expressions)

V.   D-Tree (decision tree If…Then)

The DCLASS system operates by allowing the user to first design a tree (s) for the parts(s), apply the coding syntax to the tree(s), and then enter the programme into the computer by the way of a tree source file. The user then runs the programme to check for errors, and finally tries out the system. The benefit of this system is that it increases productivity and reduces cost for the organisation that incorporates it. Another benefit is that it is easier to work with than with other hard-coded coding systems [39].

2.3.2.2.5 Vuoso-Praha Coding System

This type of coding system uses a four digit code to represent parts according to type, class, group, and material. In general, it is used for rough part classification in order to identify the type of section that would produce the part [41].

2.3.2.2.6 The CODE System

The CODE system is a parts classification and coding system that was owned by Manufacturing Data System, Inc (MDSI), Michigan, United State of America. Its most universal application is in design engineering for retrieval of part design data, but can be utilised in manufacturing process planning, purchasing, tool design, and inventory control.

The code number has eight digits [42]. For each digit there are 16 possible values (zero through 9 and A through F) that are used to describe the parts' design and manufacturing characteristics. The initial digit position indicates the basic geometry of the part and is called the major division of the code system. This digit would be used to specify whether the shape was cylinder, flat, block, or other. The interpretation of the remaining digits forms a chain-type structure. Hence the CODE system possesses a hybrid structure.

2.3.2.2.5 Opitz Coding System

The system was developed by Professor Opitz and his colleagues in Germany. The Opitz coding system uses the following digit sequence:

<p style="text-align:center">12345   6789   ABCD</p>

The basic code consists of nine digits, which can be extended by adding four more digits. The first nine digits are intended to convey both design and manufacturing data. The general interpretation of the nine digits is indicated in Figure 2.3. The first five digits, 12345, are called the "form code" and describe the primary design attributes of the part. The next four digits, 6789, make up the "supplementary code". It indicates some of the attributes that would be of use to manufacturing. The extra four digits, "ABCD", are referred to as the "secondary code" and are intended to identify the production operation type and sequence. The secondary code can be designed by the firm to serve its own particular needs [43].
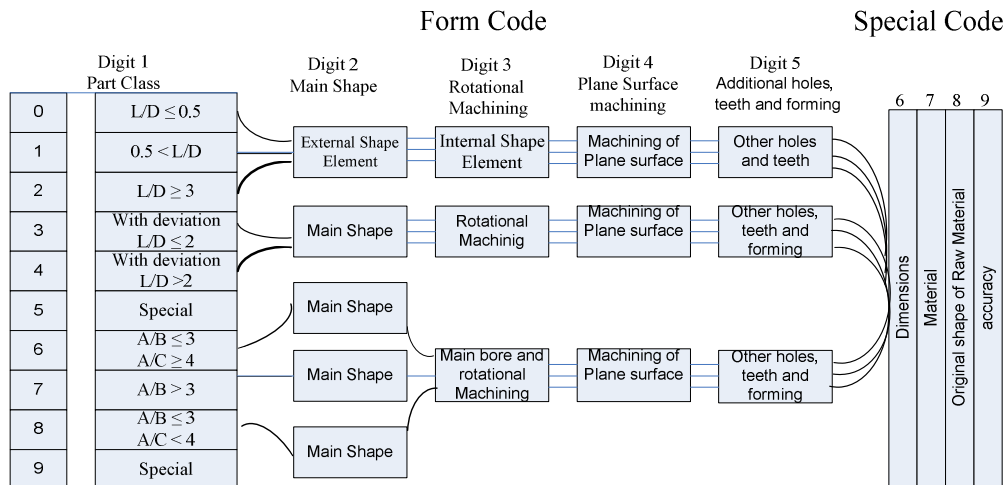
Figure 2.3: The Opitz Classification and Coding System.

2.4 Design Retrieval System

In the 1950s, a number of systems were developed to facilitate design retrieval. They became popular in Europe, especially in the United Kingdom and United States. These were systems that allowed the designer to describe a part in numeric or alphanumeric values. Design retrieval requires that the system generates a limited number of candidates so that visual inspection and selection can be readily performed by the user. When a new part is entered into the design process, the designer could code it and, with the code designation, retrieve the same or similar drawing from a file cabinet [44]. Although this system worked in conjunction with

classification and coding system, research shows that they are not part of GT applications as was earlier believed [45]. This is because the design retrieval process is focused on finding the most suitable individual component, not a family of parts as the case may be with GT.

2.4.1 Retrieval System Application

The retrieval engine is essentially an application that is designed to access data stored in the basic GT product model. In the software prototype that will be developed, the user will have one main functional interface with which to perform similarity searches to enable alternative design activities. The basic idea was that if numerical values which reflected similarities could be assigned to products, then there was a likelihood one could take some advantage of the similarities. This was done through classification and coding systems which were means of classifying parts according to similarities and assigning code numbers which showed those similarities. The code number could then be used as a tool to find groups of similar products from the database [43].

 The types of information retrievals that can be performed are based on:

1. A single attribute value: In this case the function call is usually a single database query that retrieves all object instances that have their attribute values equal to the designer specified attribute value.

2. A set of single valued attributes: In this case the function call is usually a single database query that retrieves all object instances that have a set of attribute values as specified.

3. A single attribute within a range of values: In this case the function call is usually a set of database queries that use some filtering before showing up.

4. A set of attributes each in a range of values: In this case the function call retrieves all product instances that have their attribute values within the range specified.

5. Designs that are similar to the candidate's design intent by a specified percentage: This function retrieves objects that have their important or critical attributes within the percentage specified. The results are then subjected to the Analytical Hierarchical Process (AHP) [46], [47], [48] to rank object instances. To perform such a query, it is

important at the attribute collection stage to indicate the criticality of the attributes in each object.

The retrieval system has come of age and as a result, it has found acceptance in Photo imaging, Linguistics, Parts design etc.

2.4.1.1 Photo Image Application

Photo-image industry was described by Nagao M. et al [49], Suzuki K. et al [50], Suzuki and Nagao [51], Ikeda H. et al [52] to be more effective than the use of keywords and is used in retrieving similar product images [53]. Here, the image retrieval is applied to the artistic design system for the industrial products because these products require logic of art. If the designer of industrial products pictures the actual images of the finished products and those of their applications, the images of the practical products which have been realised before are used as index images. Then products using the illustration image off a search engine and the results of the image retrieval are displayed in accordance with priority of selection for each product image.

2.4.1.2 Design of Parts Applications

The application of retrieval systems in the design of engineering parts cannot be overemphasised. When certain functionality is required in the design process, the norm is to design new parts by improving existing parts with a similar functionality. Therefore, designers usually reuse existing part designs or make reference to them when designing new parts [53]. In these cases, it is important to search for a suitable design similar to the part to be designed from the existing design library. In designing new products, the ability to retrieve drawings from the existing components is important if costs are to be controlled by preventing duplication of components and the associated design effort [54]. The wide usage of this system is linked to the fact that it prevents proliferation of parts or products thereby saving cost in designing a new one and also time for creating new parts. For instance, a designer faced with the task of developing a new part can use the design-retrieval system to determine if a similar part is already in existence. A simple change in an existing part would be much less time consuming than designing from scratch.

2.4.2 Relevance to CLD System

The relevance of similarity retrieval systems to the CLD system is that the author applied the knowledge of the retrieval system of similar parts from the database where the sketch of the part that is similar to the candidate part is drawn. This was done through the user interface to search the database in order to retrieve similar parts to the candidate's part since an aspect of realising the aim of the CLD is by suggesting a similar product code in the database to the customer/user if the product he/she requested could not be found through the first interaction.

2.5 Artificial Neural Network

Artificial Neural Networks (ANN) came out of research in Artificial Intelligence particularly from attempts to mimic the fault-tolerance and ability to learn of biological neural systems by mimicking the low-level formation of the brain [55][56]. An artificial neural network is a system based on the operation of biological neural networks, in other words, is an emulation of biological neural system. Although computing these days is truly advanced, there are certain tasks that a programme made for a common microprocessor is unable to perform; even so a software implementation of a neural network can be made with their advantages and disadvantages [57].

Advantages:

- A neural network can perform tasks that a linear programme cannot.

- When an element of the neural network fails, it can continue without any problem due to their parallel nature.

- A neural network learns and does not need to be reprogrammed.

- It can be implemented in most applications.

- It can be implemented without too much problems.

Disadvantages:

- The neural network needs training to operate.

- The architecture of a neural network is different from the architecture of microprocessors therefore needs to be emulated.

- Requires high processing time for large neural networks.

Another aspect of artificial neural networks is that there are different architectures, which consequently requires different types of algorithms, but despite to be an apparently complex system, a neural network is relatively simple.

Artificial neural networks (ANN) are among the newest signal-processing technologies in the engineer's toolbox. The field is highly interdisciplinary but the way it was adopted for the work is solely from an engineering viewpoint. In engineering, neural networks serve two important functions: as pattern classifiers and as nonlinear adaptive filters. An Artificial Neural Network is an adaptive, most often nonlinear system that learns to carry out a function (an input/output map) from data [57]. Adaptive means that the system parameters are changed during operation, normally called the training phase. After the training phase the ANN parameters are fixed and the system is deployed to solve the problem at hand (the testing phase). The ANN is built with a systematic step-by-step procedure to optimise a performance criterion or to follow some implicit internal constraint, which is commonly referred to as the learning rule. The input/output training data are fundamental in neural network technology, because they convey the necessary information to "discover" the optimal operating point. The nonlinear nature of the neural network processing elements (PEs) provides the system with lots of flexibility to achieve practically any desired input/output map, i.e., some ANN are universal mappers . There is a style in neural computation that is worth describing.
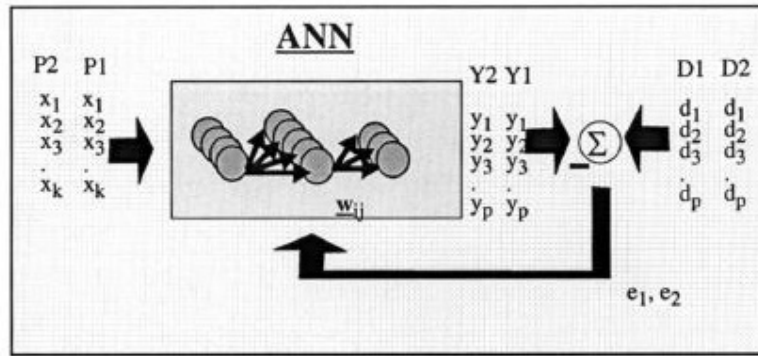
Figure 2.4: The Style of Neural Computation [57].

An input is presented to the neural network and a corresponding desired or target response set at the output (when this is the case the training is called supervised). An error is composed from the difference between the desired response and the system output. This error information is fed back to the system and adjusts the system parameters in a systematic fashion (the learning rule). The process is repeated until the performance is acceptable. It is clear from this description that the performance hinges heavily on the data. If one does not have data that covers a significant portion of the operating conditions or if they are noisy, then neural network technology is probably not the right solution. On the other hand, if there is plenty of data and the problem is poorly understood to derive an approximate model, then neural network technology is a good choice. This operating procedure should be contrasted with the traditional engineering design, made of exhaustive subsystem specifications and intercommunication protocols. In artificial neural networks, the designer chooses the network topology, the performance function, the learning rule, and the criterion to stop the training phase, but the system automatically adjusts the parameters. So, it is difficult to bring a priori information into the design, and when the system does not work properly it is also hard to incrementally refine the solution. But Artificial Neural Network-based solutions are extremely efficient in terms of development time and resources, and in many difficult problems artificial neural networks provide performance that is not easy to match with other technologies.

At present, ANN is emerging as the technology of choice for many applications, such as pattern recognition, prediction, system identification, and control.

2.5.1 The Biological Model

Artificial neural networks emerged after the introduction of simplified neurons by McCulloch and Pitts in 1943. These neurons were presented as models of biological neurons [58] and as conceptual components for circuits that could perform computational tasks. The basic model of the neuron is founded upon the functionality of a biological neuron. "Neurons are the basic signalling units of the nervous system" and "each neuron is a discrete cell whose several processes arise from its cell body". The figure below illustrates the composition of biological neuron. The neuron has four main regions to its structure. The cell body, or soma, has two offshoots from it, the dendrites, and the axon, which end in pre-synaptic terminals.
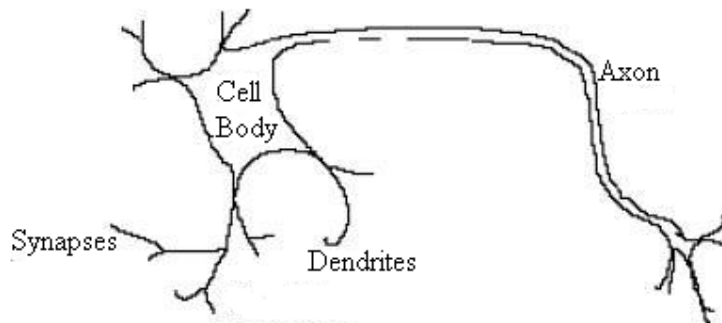
Figure 2.5: Composition of Biological Neuron [57].

The cell body is the heart of the cell, containing the nucleus and maintaining protein synthesis. A neuron may have many dendrites, which branch out in a treelike structure, and receive signals from other neurons. A neuron usually only has one axon which grows out from a part of the cell body called the axon hillock. The axon conducts electric signals generated at the axon hillock down its length. These electric signals are called action potentials. The other end of the axon may split into several branches, which end in a pre-synaptic terminal. Action potentials are the electric signals that neurons use to convey information to the brain. All these signals are identical. Therefore, the brain determines what type of information is being received

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based on the path that the signal took. The brain analyses the patterns of signals being sent and from that information it can interpret the type of information being received. Myelin is the fatty tissue that surrounds and insulates the axon. Often short axons do not need this insulation. There are un-insulated parts of the axon which are called Nodes. At these nodes, the signal travelling down the axon is regenerated. This ensures that the signal travelling down the axon travels fast and remains constant. The synapse is the area of contact between two neurons. The neurons do not actually physically touch. They are separated by the synaptic cleft, and electric signals are sent through chemical interactions. The neuron sending the signal is called the pre-synaptic cell and the neuron receiving the signal is called the postsynaptic cell. One can classify neurons by their number of processes or by their function.

2.5.2 The Mathematical Model

When creating a functional model of the biological neuron, there are three basic components of importance. First, the synapses of the neuron are modelled as weights. The strength of the connection between an input and a neuron is noted by the value of the weight. Negative weight values reflect inhibitory connections, while positive values designate excitatory connections. The next two components model the actual activity within the neuron cell. The user sums up all the inputs modified by their respective weights. This activity is referred to as linear combination. Finally, an activation function controls the amplitude of the output of the neuron. An acceptable range of output is usually between 0 and 1, or -1 and 1. Mathematically, this process is described in the figure below.
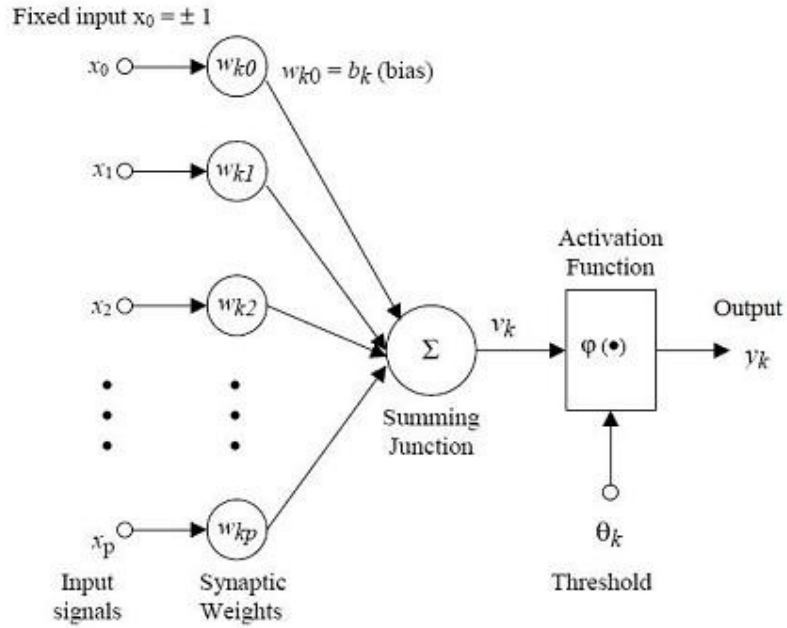
Figure 2.6: Mathematical Model of Neural Process.

From this model the interval activity of the neuron can be shown to be:

$$v_k = \sum_{j=1}^{p} w_{kj} x_j$$

The output of the neuron, y_k, would therefore be the outcome of some activation function on the value of v_k.

2.5.3 Training of Artificial Neural Networks

A Neural Network has to be configured such that the application of a set of inputs produces the desired set of outputs. There are different methods to set the strengths of the connections. One method is by setting the weights explicitly, using a priori knowledge. Another method is to 'train' the neural network by feeding it teaching patterns and letting it change its weights according to some learning rule [59]. The

second method was adopted for the purpose of designing the output generated in ranking the product similarity in this work.

The learning aspect of the Artificial Neural Network can be categorised into three distinct paradigms [60], which are:

- **Supervised learning** or Associative learning in which the network is trained by providing it with input and matching output patterns. These input-output pairs can be provided by an external person, or by the system which contains the neural network (self-supervised).
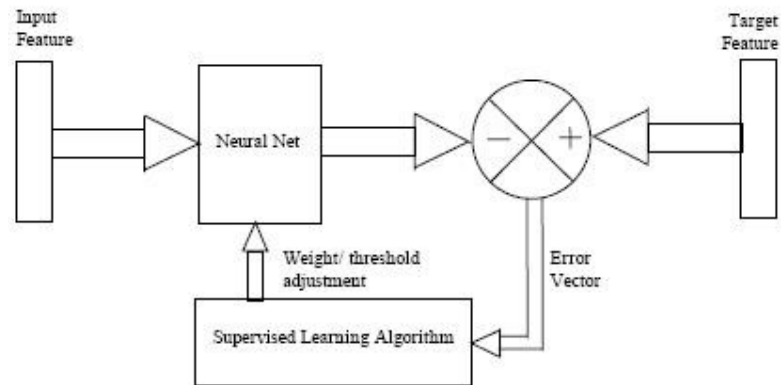
Figure 2.7: Supervised Learning Structure of ANN [59].

- **Unsupervised learning** or Self-organisation in which an (output) unit is trained to respond to clusters of pattern within the input. In this paradigm, the system is supposed to discover statistically salient features of the input population. Unlike the supervised learning paradigms, there is no a priori set of categories into which the patterns are to be classified; rather the system must develop its own representation of the input stimuli.
- **Reinforcement Learning** This type of learning may be considered as an intermediate form of the above two types of learning. Here the learning machine does some action on the environment and gets a feedback response from the environment. The learning system grades its action good or bad based on the environmental response and accordingly adjusts its parameters.

Generally, parameter adjustment is continued until an equilibrium state occurs, following which there will be no more changes in its parameters.

The ANN was adapted for this study because it can be used in the retrieval system of similar products [61] and was also used as an alternative to weighing factors used in the manual retrieval process of similar product codes.

2.6 Conclusions

This chapter has highlighted the approach used nowadays to fulfilling customers' demand in customisation environments, reduction in the lead time of a product through group technology, retrieval of similar designs to reduce cost and through supervised learning of artificial neural networks to determine the desired output. The review of literature has expounded the applications of these methods. The outcome of the review is that these methods or technologies are proven to be successful tools in addressing their areas of applications. Customisation has helped in cost cutting in mass production manufacturing and helped to some extent the level of customer input in designing of their products. Group Technology has proven to be a very important tool in manufacturing and production systems. It helped in improving the productivity by grouping parts with similar features into families and forming production cells with grouping of dissimilar machines and processes. The design retrieval system allows the designer/user to retrieve the same or similar drawings or parts from the parts/drawings database. And finally, the Artificial Neural Network has important tools that help the designers in determining the end-result (output) of their input data. However, some of the limitations of the methods are:

- Customers have not been given much flexibility they required when it comes to customisation of their product.

- Some approaches have not be implemented outside of data and design drawings.

- Classification systems have not been used to integrate both the hierarchical and chain type system.

CHAPTER THREE
THE CLD SYSTEM APPROACH

3.1 Introduction

Based on the literature review that has been conducted as presented in Chapter Two, it can be reiterated that:

1. Most of the research, if not all, that has been carried out on Customisation has only been able to address one issue which is allowing the customers/users to customise their desired product from a pre-defined template or catalogue, in which case they are unable to express their idea about their ideal product and thereby constraining their choice. Though customisation has been implemented in some consumer products it has not been extended to mechanically oriented products and services.

2. From all indications, Group Technology has merely been based on classifications and coding of engineering parts and drawings without considering the products in its classification and coding. The hierarchy used in classification can only work for a particular item thereby limiting its options for variety of products.

3. The retrieval system as popular as it is, has not been tried or used outside data, drawings and part retrieval. Therefore, with this in mind one can say that the application of the retrieval system to a Customer-Led Design System is new because it was used for similarity of product codes and not data or part codes.

4. In the case of the Artificial Neural Network, its supervised learning paradigm was the main reason it was used for the work. This was to automatically generate the similarity index which will cater for the short-come of the Weight Factor method used for the retrieval system based on the input parameter and the expected output because it has the capability of allowing the designer to provide the system with input and matching output patterns.

In order to overcome these limitations and involve customers as co-designers and to allow them to bring their ideals to reality, a new system is introduced by the author to fully integrate the customer/user into designing using a CLD system.

The main aim of this chapter is to introduce the approach used to develop the CLD system. Each of the methods and attributes is further described. The chapter explains the development of CLD and deals with steps to be taken to actualise the system, (Section two), and the overview of CLD which is subdivided into: the hybrid system of classification with its nine attributes (sub-section one), mechanical design coding system for the coding used (sub-section two), and the products module library or database (sub-section three).

3.2 Developing the CLD System

The Customer-Led Design System is intended to be a system that will give the customers/users the flexibility, creativity and influence they desire in bringing their desired product to reality which were not part of a similar system. It will allow them to select from different family of products, retrieve a similar product type from the system database if the intended product is not found and modify it to their desired product type. The designing of a Product Chain System (PCS), a hybrid type of classification system, is very critical since it is the defining factor for a variety of family of products. The development of the nine attributes constitutes the next step followed by the coding system for the mechanical design and how to suggest a similar product to the customers/users through the similarity retrieval system, if their required product is not found. This then allows them to modify the existing product found in the product module library. However, the scope of the research has been limited to consumer products and services. It also researched for products that are mechanically oriented in nature and not for "parts or non-mechanical products".

The PCS consists of product attributes that are developed to form the hybrid (chain-hierarchical type of classification) system which affords the customers/users the opportunity of a wide-range of product options to select from. The PCS is based on nine chain-hierarchy attributes as follows - Application which is function based and is the most important attribute because of its features, External motion which has to do with product visible motion, Internal motion describes the internal movement of

the products, Energy sources show what kind of energy the product uses if any, Shape of product describes the product's form, Power rate indicates the wattage of the product if it is being powered, Weight indicates the heaviness of the products, Maximum dimension describes the products size based on it maximum size, and the Material of which the products are made.

The GT coding structure consists of hierarchical, chain type and hybrid codes. The code type adopted for this system is the hybrid-type structure. With the hybrid selected, the author was able to combine the mixture of hierarchy and chain type to develop the PCS of the CLD system. This makes it comprehensive to allow for the variety of products which will help the customers in defining exactly what they want by systematically following the defined steps through interaction with the system.

3.3 The Overview of the Customer-Led Design System

This section explains in details each step in the development of the system.

3.3.1 Hybrid System of Classification

The goal here is to develop a systematic product classification system that supports the development of appropriately specialised product chain system for the modelling of a CLD system. The hybrid (chain-hierarchy) system that is used to classify the products is a detailed hierarchical system called Product Chain System (PCS) that makes use of such attributes as Applications, Motions - external and internal, Energy Source, Power Rate, Maximum Dimension, Weight of the Product, Product Shape and Material from which the product is made as has been mentioned above to draw information about the product from the customer. Each of these attributes has classes and subclasses in hierarchical order which help to determine and narrow down the customer's product just like a Decision Tree Classification. The hybrid also allows both vertical and horizontal cross reference of features or attributes of the products irrespective of other characteristics, that is, relating one attribute feature to another position of such attribute or sub-attribute in the hierarchy notwithstanding [4].

The PCS attributes structure is shown in figure 3.1a and 3.1b below. Figure 3.1a illustrates the simple structure of the principal attribute features which only indicate

the first hierarchy of the system, while in figure 3.1b the whole complex structure of the system is illustrated. This shows the sub-classes of each attribute in its entirety.

How the attributes of Product Chain System structure are combined together, to generate a desired product for the customer/user is discussed in Chapter Four of this work.
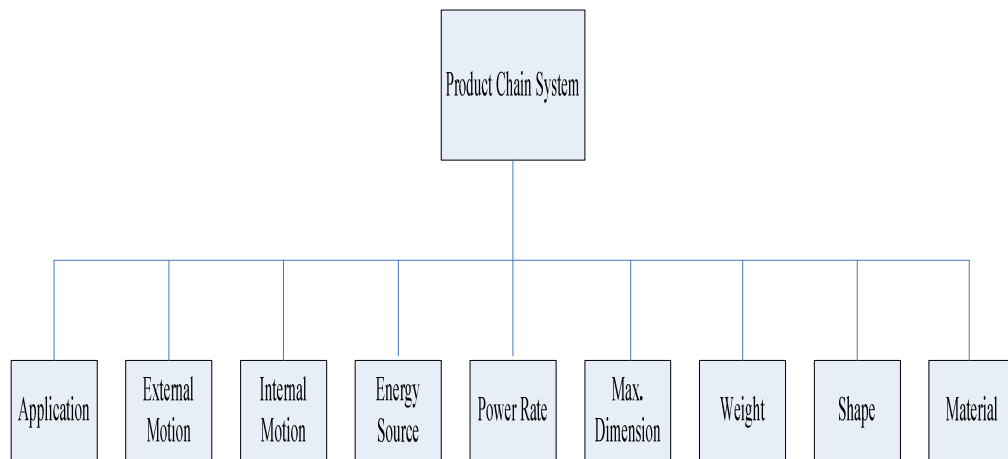
Figure 3.1a: Product Chain System Attributes
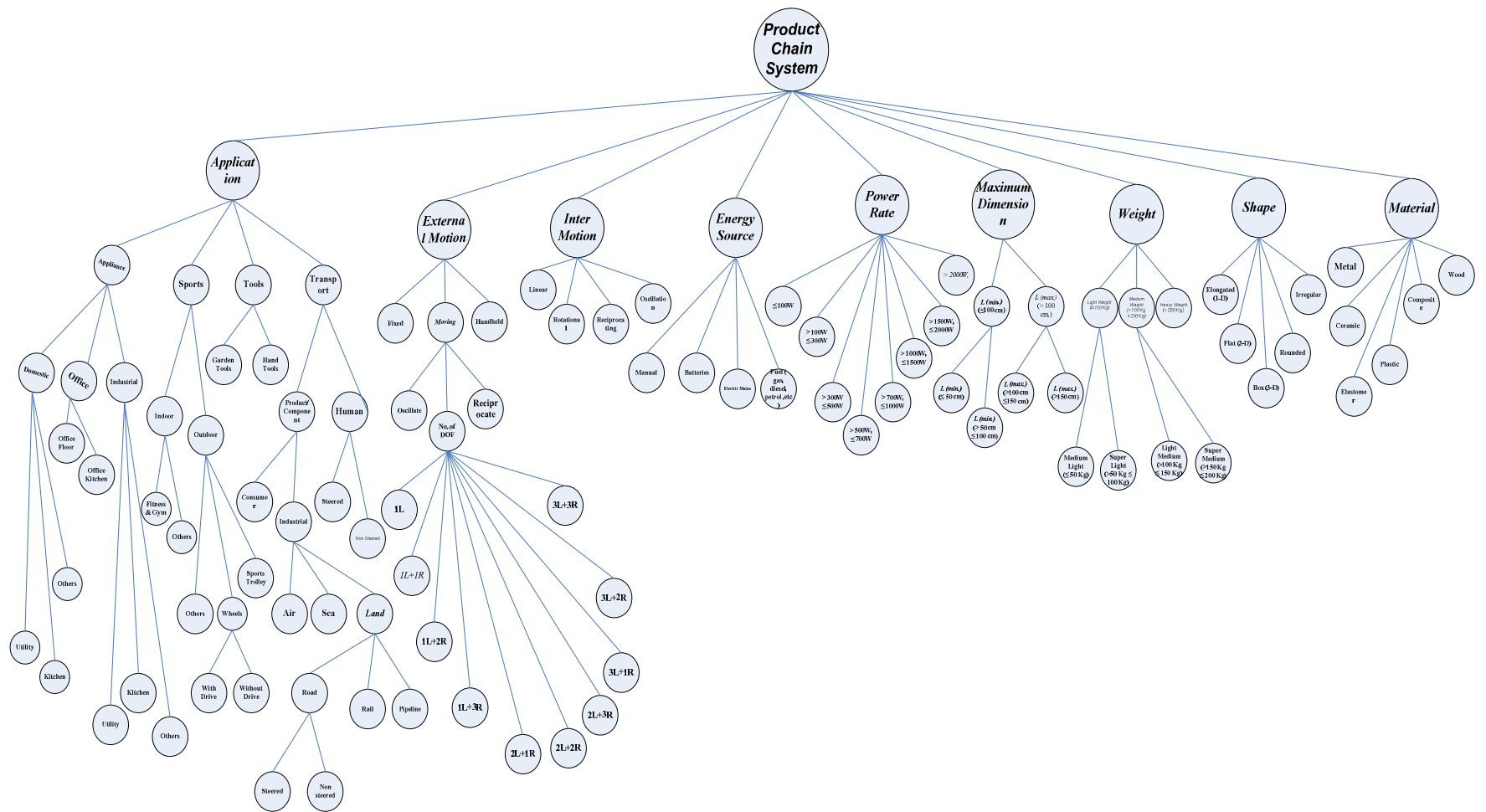
Figure 3.1b: Product Chain System Attributes with Sub-Groups

3.3.1.1 Product Application Attribute

This is a function-based attribute that defines the products and classifies them in hierarchical order according to their uses. The main application attributes structure is illustrated in figure 3.2 below. The product classes are:

- Appliance: The term *appliance* became known in the early 1900s when electricity started to power household devices. Before then, electric motors were used as source of power for many devices. An appliance was at first considered a luxury because an expensive and multipurpose component (the electric motor) was used for a limited single purpose. According to Merriam-Webster Online, the first definition of appliance is the "act of applying" [62] which means to put to use for a practical purpose. The second definition is a piece of equipment (tool or device) "designed for a particular use or function" [62] to enable the act of applying. In general terms, an appliance is a *solution* to solving a problem by enabling the proper function. For this reason, the evaluation of an appliance involves judgments about the completeness and effectiveness of the solution. For the purpose of this work, the term *appliance* will be defined as "*equipment (product) that is designed for a special purpose and enables a practical function*" [63]. This refers to products that find application as a device or machine for performing a specific task, especially one that is worked mechanically or by electricity. The appliances are sub-classified as:

*(i).*Domestic: in this sub-class are Utilities Products such as washing machine, dryer, etc., Kitchen Equipment/Products such as toaster, microwave, etc, and Other Products or equipment that are not classified under the first two domestic products/equipment.

(ii). Office: in this sub-class are products/equipment that are used in the office. Such equipment is classified into Office floor products, that is, products/equipment that are used on the office floor such as fans, and Office Kitchen products such as microwaves, toaster etc. and,

(iii). Industrial: products that are used in industries are classified under this. These are heavy duty equipments or products. The industrial appliances are sub-classed into Utilities Products such as industrial washing machine and dryers (used in laundry businesses), Industrial Kitchen Equipment/Products such as Oven, hob, etc, and Other Industrial Products or equipment that are not classified under the first two industrial products/equipment.

All products in this category are contained in the product module library (database) of the CLD System.

- Sports: for products that are used in the sports environment. Sports equipment is a general term for any object used for sport or exercise. These products are classified into Indoor sports and Outdoor sports.

(i). Indoor: these are products/equipments that are used for indoor sports. These products are classified into fitness and gymnastic equipment, and other indoor product,

(ii). Outdoor: these are products/equipments that are used for outdoor sports. These products are classified into wheel-based products, sport trolleys and others. The wheel products are further classified as the ones with drive (e.g. gear, chains or belt drives) which propel them for motion and an example of such product is a bicycle and the ones without drive, such as a wheelchair and a scooter.

The structure of Sports product/equipment as contained in the main application attribute is shown in figure 3.2 below.

- Tools: A tool on its own can be said to be an instrument used in the physical arts, to facilitate mechanical operations [64]. The products for this application are classified or grouped into

(i). Garden tools, and

 (ii). Hand tools.

 Products under this category are stored in the database as well. The grouping as contained in the application attribute structure is illustrated in figure 3.2.

- Transportation: this is the act of transporting, or the state of being transported; carriage from one place to another; removal; conveyance [65].

The field of transport has several aspects: loosely they can be divided into three groups, namely: infrastructure, vehicles, and operations.

(i). Infrastructure includes the transport networks (roads, <u>railways</u>, airways, canals, pipelines, etc.) that are used, as well as the nodes or terminals (such as airports, railway stations, [66] bus stations and seaports).

(ii). Vehicles generally ride on the networks, such as automobiles, trains, airplanes.

(iii). The operations deal with the control of the system, such as traffic signals and ramp meters, railroad switches, air traffic control, etc, as well as policies, such as how to finance the system (e.g. use of tolls or gasoline taxes in the case of highway transport).

In the context of this work, any product that can be use for performing the acts of transporting or conveyance of human and consumer goods from one place to another is what this sub-section is all about. These products are grouped into product/component and human depending on what is being transported.*(i).* Product/component transportation: This belongs to the first two division of transportation as stated above. The product/component has many hierarchies. The sub-classes are Consumer and Industrial. If it is for industrial usage, then we classify industrial into Air (products that can be used for transporting components by air), Sea (products that can be used for sea transportation of components) and land (products that can be used for transporting components through land). The Land sub-class is further sub-grouped into Rail, Pipeline, and Roads (products essential for the movement of goods and services through the road network). Road is also sub-classified into Steered such as hand truck, pallet jack, or Non-Steered such as AGV, crane, conveyor.

(ii). Human transportation. The human group is further classified into Steered such as bicycle, scooter, and Non-Steered such as elevator, moveator.

However, the application attribute can be enlarged to hold as many attributes as possible. There is no limitation to these functionality- based attributes.
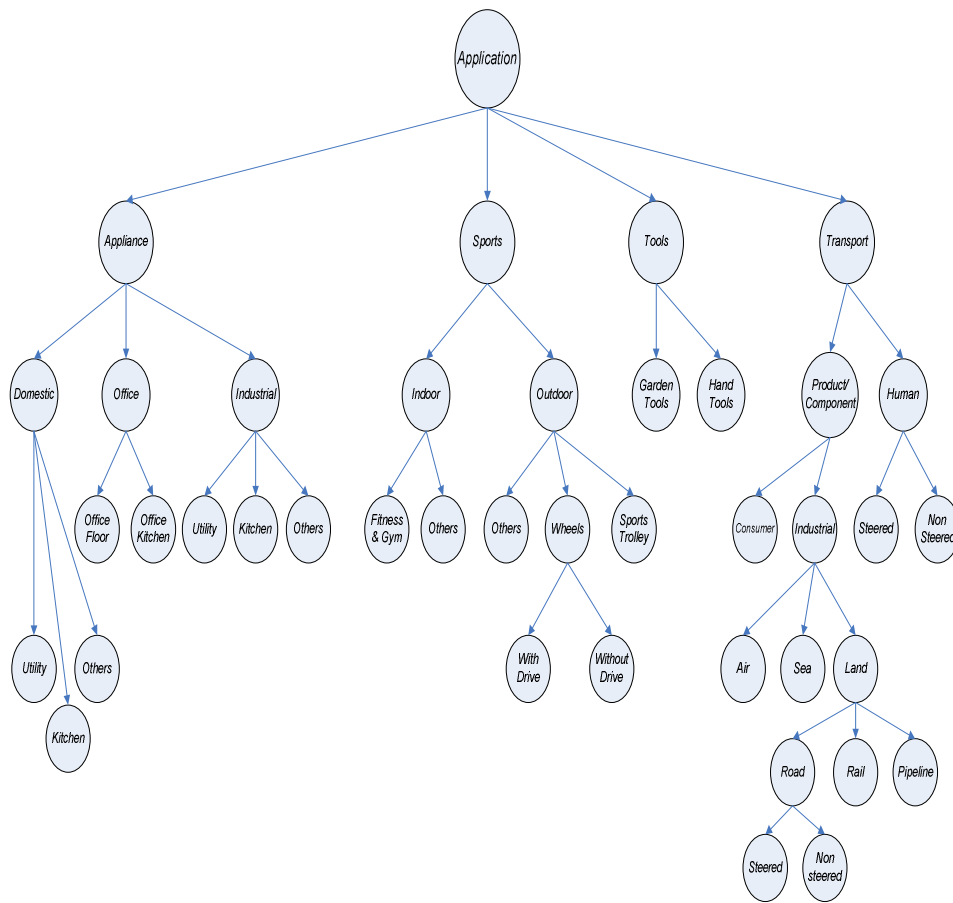
Figure 3.2: Application Attribute

3.3.1.2 External Motion Attribute

Another attribute of the PCS is the External Motion which defines the products in relation to what visible motion or movement the products have. This attribute defines and analyses the product to see whether it is movable or not and then cross references it with other attributes for further analysis [4]. The External Motion attribute classifies the motion based on the following:

(i). Fixed: It is fixed if no relative motion can be seen from outside, that is, when looking at the product, it is based in one position during application. Examples of such products include toasters and microwaves.

(ii). Moving: It is *moving* if it has motion relative to the number of degrees of freedom (DOF) and *reciprocating* motion, this kind of motion is found in products such as bicycles, scooters, wheelbarrows, pallet trucks etc.

(iii). Hand-held: Hand-held as a result of motion by reason of handling e.g. stapler, electric tin-cutter [67].

Figure 3.3 illustrates the hierarchical structure of this attribute.
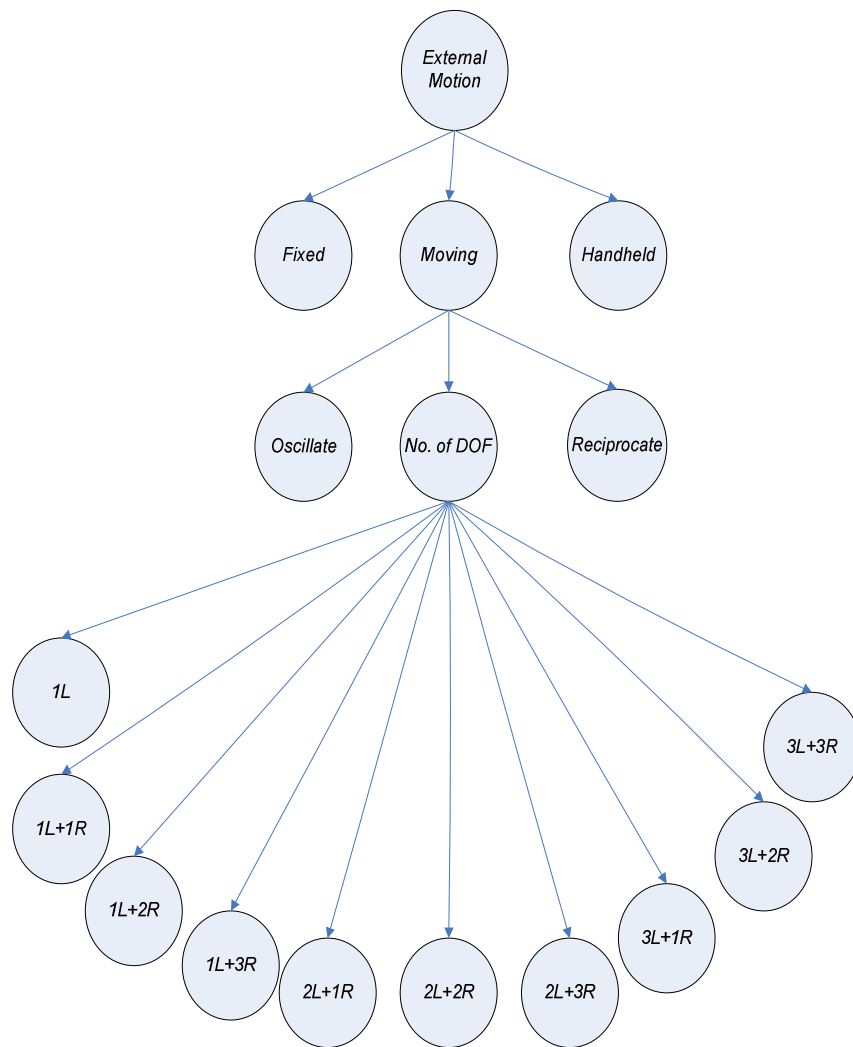
Figure 3.3: External Motion Attribute

3.3.1.3 Internal Motion Attribute

This attribute like the external motion defines and analyses the product to see whether it is movable or not and then cross references it with other attributes for further analysis. The Internal motion attribute has to do with internal motion of the products and it is classified into:

(i). Linear - This type of motion is the most basic of all motions. Linear motion is motion along a straight line and can be described mathematically using only one spatial dimension. There are two types of linear motion analysed in the products and these are rolling-element (wheel) and plane (slide).

(ii). Rotational – A kind of motion in which the products internal linkages remain located (more or less) at the same spatial position but constantly changes its orientation with respect to other fixed points in space [68]. Rotational motion is the starting point for many mechanisms.

(iii). Reciprocating- This type of motion involves the back and forth movement. Many descriptions of this type of motion in a product include forward & backwards, up and down , side to side but in a straight line [69]

(iv). Oscillation - Oscillation tends to be an ending point for a mechanism rather than the starting point. An oscillating motion existing in a product is the kind of motion that moves forwards and backwards in an arc or circle repeatedly. It is different from the reciprocating motion in which motion is forward and backwards but in a straight line repeatedly.

These all describe the way the internal linkage in the product that causes or results in motion operates. Figure 3.4 below shows the grouping of the internal motion.
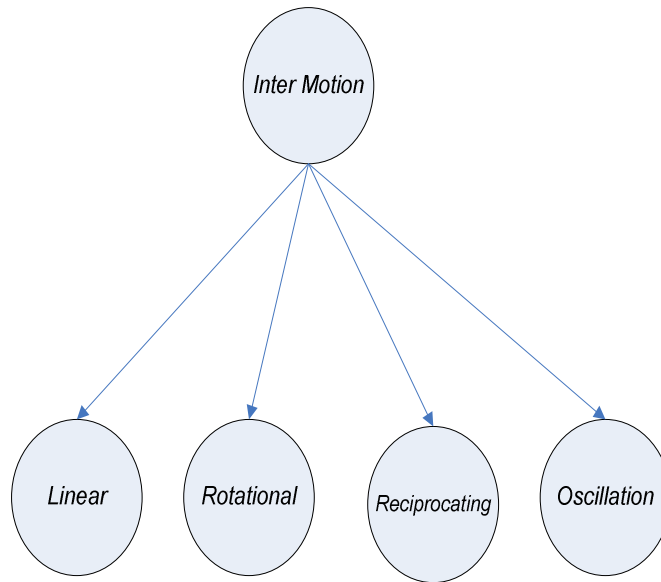
Figure. 3.4: Internal Motion Attribute

3.3.1.4 Energy Source Attribute

The source of energy as related to the product is determined by the relativity of the products' motion to either external or internal motion. That is, the energy source for the product is dependent on the Motion attributes. The energy source can be classified into -

(i). Manual - these are products that are operated solely by a human . They require no external energy source. Examples of such products are bicycle, pallet truck, exercise bike etc.

(ii). Batteries - these are products that are mainly operational through the use of batteries such as electric bikes, electric scooters etc.

(iii). Electric mains - for products that are mainly operated through electricity. Examples of such products are power tools, lawn mower, microwave etc.

(iv). Fuel - this is for products that use gas, petrol or diesel to operate. Examples of such products are power tools, lawn mowers, etc.

The classification structure of the energy source can be seen in figure 3.5 below.
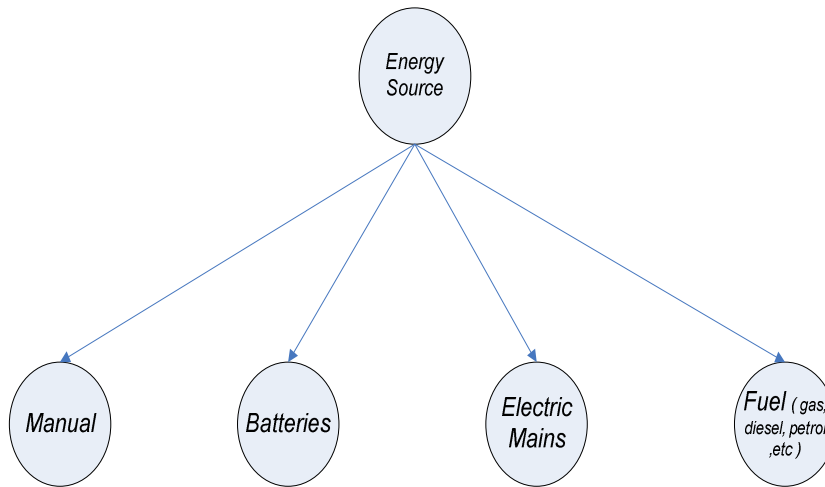
Figure 3.5: Energy Source Attribute

3.3.1.5 Power Rate Attribute

Since different products have different energy requirements, this attribute gives the description of the amount of energy required by the products if the product's energy source is not manual. If a product is manually operated, its power rating will be zero, that is, no power rate is applicable. The Power rate attribute is dependent on the energy source and therefore cannot function alone. The classification of this attribute is shown in figure 3.6 below and the unit of measurement is in Watts. The power rates attribute is classified in ranges starting from products that are less than 100 watts for the first range, those that are greater than 100 watts but less than 300 watts for the second range, those that are greater than 300 watts but less than 500 watts for the third range, those that are greater than 500 watts but less than 700 watts for the fourth range, those that are greater than 700 watts but less than 1000 watts for the fifth range, those that are greater than 1000 watts but less than 1500 watts for the six range, those that are greater than 1500 watts but less than 2000 watts for the seventh range, and the last range of the attribute is for the products with power rates from 2000 watts and above.

53
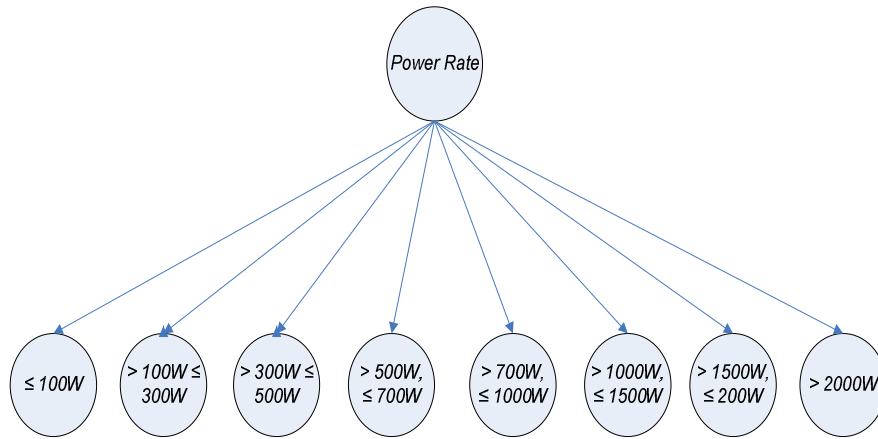
Figure 3.6: Power Rate Attribute

3.3.1.6 Maximum Dimension Attribute

This attribute defines the product size based on length by breath by width (l x b x w). Maximum Dimension gives expression to the product by indicating its proportion. Though as stated above the product sizes are based on l x b x w, however, for this work the side of the product with the longest (maximum) length/dimension is chosen in selecting the dimension for the products. This is because every product will have a varying dimensions in l x b x w and as a result, it will be very complex to classify and assign the dimensions. The grouping of the dimension attribute into minimum length *(L min.)* which also has sub-classes for simplicity reasons and that of maximum length *(L max.)* with sub-class of its own is shown in figure 3.7. The unit of measurement is in centimetre *(cm)*.
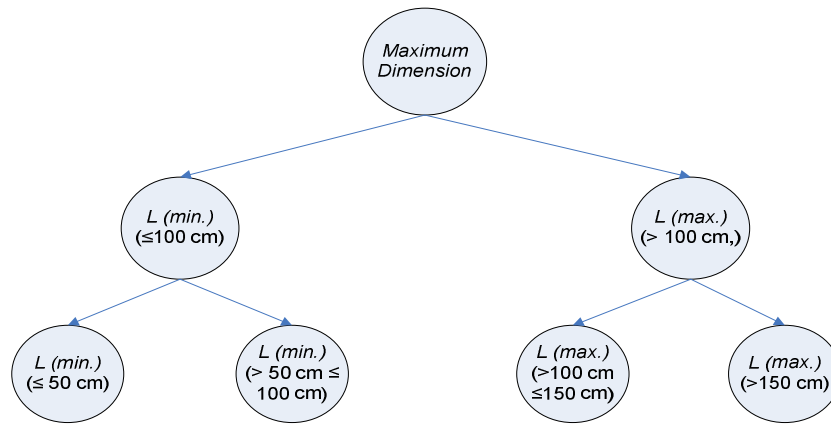
Figure 3.7: Maximum Dimension Attribute

3.3.1.7 Product Weight Attribute

Another way of capturing the exact product(s) that the consumer wants is by incorporating the product weight attribute into the PCS. This also helps in further narrowing down the consumer's order to exactly want he/she had in mind. The weight attribute is used to define and classify the products' weight into various groups based on how heavy the products are. The weight attribute is classified into three groups in a hierarchical order as shown in figure 3.8. The first group is Light Weight which represents products that are less than or equal to 100 Kilograms in weight, and this also is sub-grouped into; Medium Light Weight for products less than or equal to 50 Kilograms and Super Light Weight for products that are greater than 50 Kilograms but less than or equal to 100 Kilograms. The second group is Medium Weight which defines products that are greater than 100 Kilograms but less than or equal to 200 kilograms. This is further sub-grouped into - Light Medium Weight for products greater than 100 Kilograms but less than or equal to 150 Kilograms and Super Medium Weight for products greater than 150 Kilograms and less than or equal to 200 Kilograms. The third group is the Heavy Weight which represents products that weighs 200 Kilograms and above. The reason for this classification of weight is that it will give further distinction to products' weights since no one product has the same weight and also for simplicity in grouping [70].
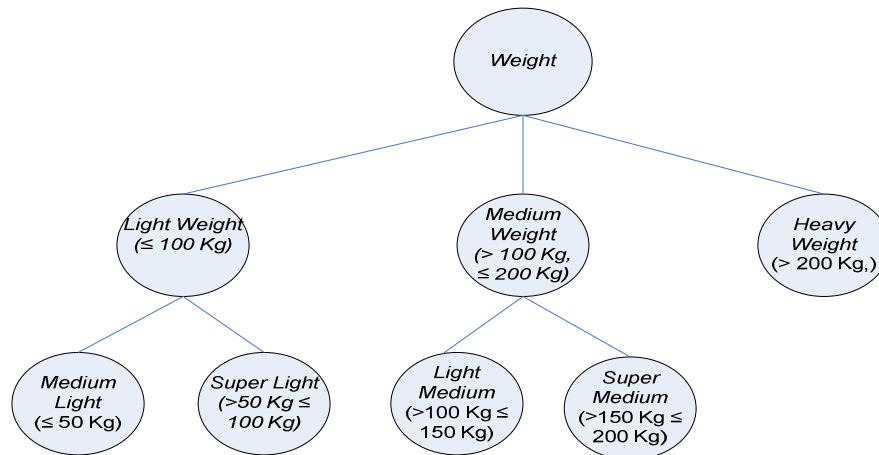
Figure 3.8: Weight Attribute

3.3.1.8 Product Shape Attribute

The Shape attribute assists the customer with the choice he/she desires for the product's form - the shape. This helps to give distinction to various products as they vary in form. The Product Shape is sub-classified into five groups as shown in figure 3.9.

1. Elongated Shape (1-D) - products that are rectangular, polygons, cylindrical in forms.

2. Flat Shape (2-D) - products that are plane, star and pentagon in form.

3. Box Shape (3-D) - products that are cones, cubes and oblong in form.

4. Rounded shape - these are circles, bulbs, ovals, and globes.

5. Irregular shape – products in this category include every other shapes/forms that could not fit into the other categories above.

The Shape attribute might not necessarily depend on other attributes but works as part of the Hybrid Classification in the Product Chain System.
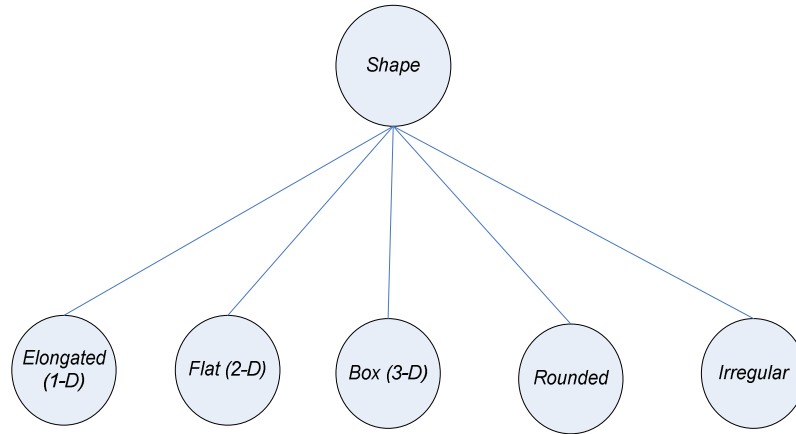
Figure 3.9: Shape Attribute

3.3.1.9 Product Material Attribute

This attribute describes the type of materials the products are made out of. This attribute gives a clear distinction of the various products and aids in narrowing down the customers/users selection to the least available products in the database. Figure 3.10 shows the Material attributes used. Materials are grouped into the following categories -

1. Metals: this consists of any products made of this constituent that finds application as household conveniences, electrical products, transportation products, tools etc.

2. Ceramics: this type of material is widely used in household products, garden tools, engine applications for precision products and for products that require properties such as extreme wear, corrosion, heat resistance, high strength, physical stability and a wide range of electrical properties

3. Elastomer: this material type is used to characterise products that have high degree of flexibility and elasticity.

4. Plastics: this type of material has wider application in consumer clothing, housing, automobiles, aircraft, packaging, electronics, signs, recreation items, and medical implants to name but a few of its many applications [71].

5. Composite: these are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure [72]. This is used in high-performance products that need to be lightweight, yet strong enough to take harsh loading conditions e.g. bicycle frames, boats etc.

6. Wood: this is the most versatile, renewable and sustainable material resource known to man when compared to other materials [73]. Since time began humans have used wood in every area of their survival - shelter, tool craft, transport, cooking and warmth. Wood can be said to be a heterogeneous, hygroscopic, cellular and anisotropic material. The engineered wood products prove to be more environmentally friendly and sometimes cheaper than building materials such as steel or concrete. In the context of this work, the usage of wood will be limited to products that are mechanically oriented. One such example of using wood for mechanically oriented products is in skateboards where the base of the skateboard is made from wood.
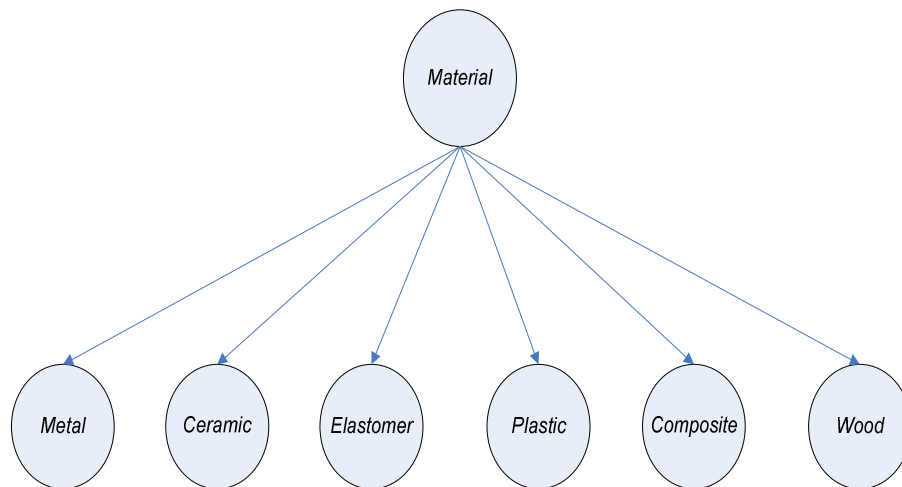
Figure 3.10: Material Attribute

3.3.2 Mechanical Design Coding System (MDCS)

As noted from the literature review, coding systems have been in operation over the years and their benefits to the manufacturing industry cannot be overemphasised. Every manufacturing or engineering enterprise that deals with product design will find the coding system useful because of its benefit in part identification which makes retrieval of existing parts from the database easier. As a consequence for this work, the coding system is of paramount importance in achieving the Researcher's objective as stated in Chapter One.

Another aspect of the CLD is the Coding System for Mechanical Design which assigns a symbolic description (code) to the products in the hybrid (combined hierarchical and chain-type) classification system. The main characteristic that is required in designing the Products Coding System is the flexibility because customers want to be able to select products from different options and build their own individualised products and since no two customers have exactly the same needs and that various customers' needs may have conflicting requirements [74].

In installing the coding system for mechanical design, there are three methods for going about this:

- purchasing a commercial package from a vendor;

- modifying a publicly available system to fit the required purposes; and

- developing an original system based on the analysis of samples parts [74].

The second method was adapted for the purpose of this work. The Opitz coding system [36] was modified to suit the Mechanical Design Coding System (MDCS) used for this work. This is because Opitz coding system was initially developed for the investigation of components statistics [75] but has since been used for design retrieval [76] and other group technology applications. Opitz is a mixed coding system of Monocode and Polycode in that the monocodes allow a vertical search while the polycode enables a horizontal search across the board irrespective of other characteristics [77]. This cross references as was earlier mentioned above under the hybrid system of classification makes the Opitz coding system the suitable choice for the purpose of this work.

The modification that was carried out on the Opitz coding structure is explained below.

The Opitz coding system consist of three groups of digits as can be seen in Table 3.1

Table 3.1: Groups of Opitz Coding System and their Functions.

	Digits	Functions
FORM CODE	12345	Design Attributes of the Part
SUPPLEMENTARY CODE	6789	Manufacturing Attributes
SECONDARY CODE	ABCD	Production and Operation Sequence

The Form and Supplementary codes in Opitz coding constitute the Basic Codes but in MDCS, the basic code represents the Application attribute which is the most important in the CLD system while every other attributes of the CLD system are categorised to be Supplementary codes. In this work, the secondary code was not considered but might be of good use when thinking of expansion to the CLD System in the near future. The nine digits Opitz coding was replaced with nine alphabet letters with each representing one attribute per hierarchy. The MDCS is shown in Table 3.2 below.

Table 3.2: Mechanical Design Coding Structure (MDCS)

LETTER	ATTRIBUTES	CODE TYPE
A	Application	BASIC
E	External Motion	Supplementary
I	Internal Motion	Supplementary
S	Source of Energy	Supplementary
P	Power Rates	Supplementary
D	Maximum Dimension	Supplementary
W	Weight	Supplementary
F	Shapes of Product	Supplementary
M	Materials	Supplementary

Furthermore, Table 3.3 below analyses the Opitz coding system by describing the form and supplementary code digits. It also shows the result, that is, the Mechanical Design Coding System of the modification carried out on the Opitz structure, where the dependency of each attribute with respect to each other is indicated.

Table 3.3: Difference between Opitz and MDCS

OPITZ		MDCS	
Digit		Letter	
1 Form Code	General shape of workpiece that is, the "part class".	A Form Code	Application is the main attribute
2 Form Code	External shape and relevant form elements. It depends on the first digit.	E Supplementary Code	External Motion depends on the Application attribute
3 Form Code	Internal shapes or main bores. It also depends on the first digit.	I Supplementary Code	Internal Motion depends on Application but not necessarily on External Motion
4 Form Code	Surface plane machining.	S Supplementary Code	Source of Energy depends on Application but independent of E & I
5 Form Code	Auxiliary holes and gears types.	P Supplementary Code	Power Rates depends on Application and Energy Source
6 Supplementary Code	Diameter or length of work piece.	D Supplementary Code	Maximum Dimension depends on Application
7 Supplementary Code	Workpiece material.	W Supplementary Code	Weight depends on Application and Max. Dimension
8 Supplementary Code	Shape of raw materials.	F Supplementary Code	Shapes of Product depends on Application
9 Supplementary Code	Workpiece accuracy.	M Supplementary Code	Material depends on Application and other attributes except Max. Dimension.

The application of MDCS to the Product Chain System structure helps in making each product attributes unique, comprehensive and easy to retrieve from the product module library. The coding system works by giving each item of the Application attribute a unique code with a letter A at the front representing the attribute and every other sub-group in the Application hierarchy will be represented by a digit according to their position in the hierarchy which might result in a very large number of codes. This will be arranged into a framework such as groups, classes and subclasses, and as a result, customers will be able to select products from various applications to build their own individual product(s). The coding structure for the application attribute [78] is illustrated in figure 3.11. For example, from Figure 3.11 the letter and digits of code A2221 are interpreted as a product with wheel(s) that includes a drive system which could be used for outdoor sport purpose.
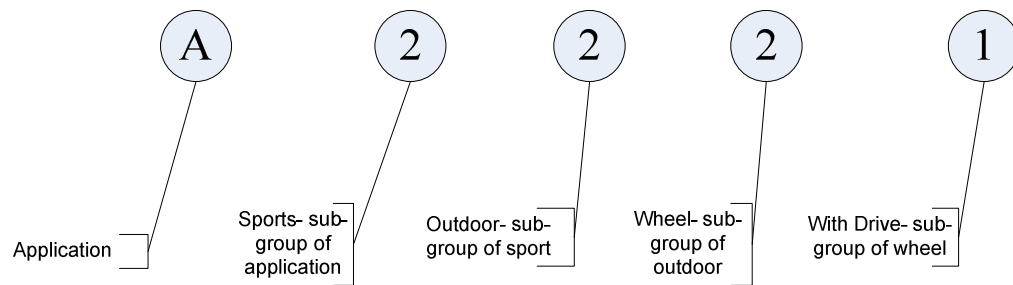
Figure 3.11: Interpretation of Application code.

Also, the same modality is applicable to other attributes in the Hybrid Classification System with each attribute starting with a letter and then the sub-groups with digits.

For External Motion, it has three level or sub-class of hierarchy. So, for this attribute letter E will represent the attribute and the sub-group in the hierarchy will be represented by a digit according to their position in the hierarchy. The coding structure for the External Motion attribute is illustrated in Figure 3.12. For example, from Figure 3.12 the letter and digits of code E228 is interpreted as a product having an encompass movement in all straight motion and a turn in one direction.
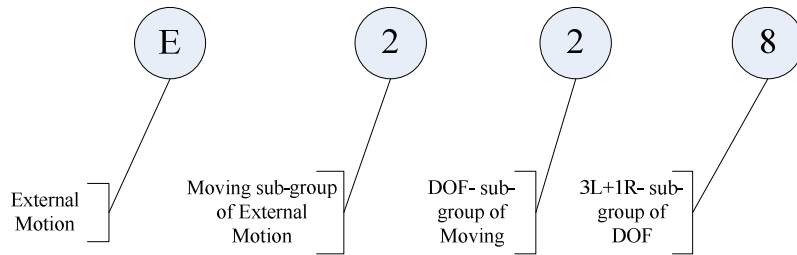
Figure 3.12: Interpretation of External Motion code.

Internal Motion has only one level or sub-class of hierarchy. For internal motion, I will represent the attribute and the sub-class in the hierarchy will be represented by a digit in the hierarchy. The coding structure for the Internal Motion attribute is shown in Figure 3.13. The letter and digit of code I1 from Figure 3.13 is interpreted as having a linear inner motion.
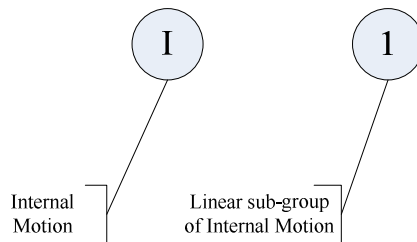
Figure 3.13: Interpretation of Internal Motion code.

For Energy Source, it has one level or sub-class of hierarchy. Alphabet letter S is used to represent the attribute and the sub-group in the hierarchy will be represented by a digit based on its position in the hierarchy. The coding structure for this attribute is illustrated in Figure 3.14. For instance, from Figure 3.14 the letter and digit of code S3 is interpreted as the product uses electricity for its energy source.
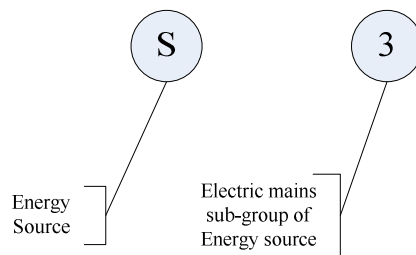
Figure 3.14: Interpretation of Energy Source code.

The Power Rate attribute has one level or sub-class of hierarchy and it can be denoted with a letter P. The sub-group in the hierarchy will be represented by a digit based on its position in the hierarchy. The coding structure for the Power Rate attribute is illustrated in Figure 3.15. For example, from Figure 3.15 the letter and digit of code P5 is interpreted as the product's power output is between 700W to 1000W.

P 5

Power Rate

> 700w≤1000w
sub-group of
Power Rate
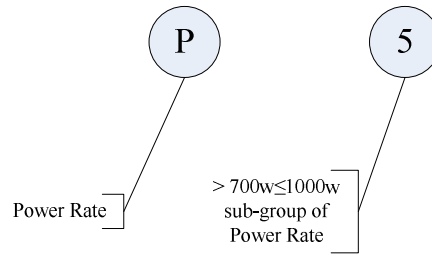
Figure 3.15: Interpretation of Power Rate code.

For Maximum Dimension, it has two levels or sub-class of hierarchy. The alphabet letter D will be used to represent the attribute, and the sub-group in the hierarchy will be represented by a digit according to their position in the hierarchy. The coding structure for the Maximum Dimension attribute is illustrated in Figure 3.16. For example, from the illustrated structure in Figure 3.16, the letter and digits of code D21 are interpreted as product of 100cm in length.

D 2 1

Max.
Dimension

L (min.) sub-group
of Max.
Dimension

l (min.) sub-
group of L
(min.)
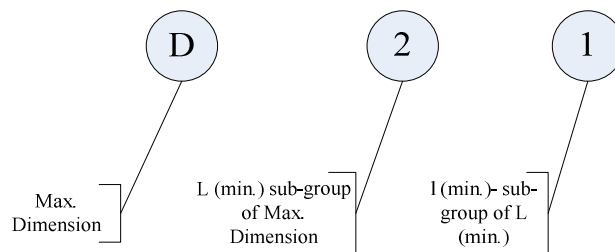
Figure 3.16: Interpretation of Maximum Dimension code.

Weight also has two levels or sub-classes of hierarchy. For this attribute, letter W will represent the attribute and the sub-group in the hierarchy will be represented by a digit according to their position in the hierarchy. The coding structure for the Weight attribute is illustrated in Figure 3.17. For example, from Figure 3.17 the letter and digits of code E228 are interpreted as a light weight product of 50Kg to 100Kg.
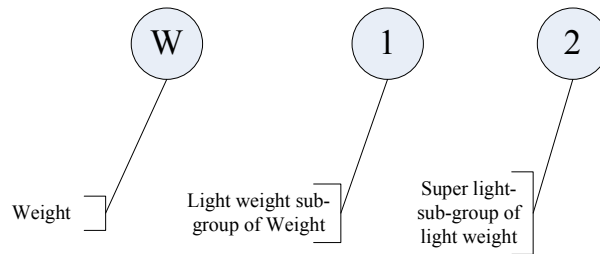
Figure 3.17: Interpretation of Weight code.

For Product Shape, it has one level or sub-class of hierarchy. For this attribute, letter E will represent the attribute and the sub-group in the hierarchy will be represented by a digit according to its position in the hierarchy. The coding structure for the product shape attribute is illustrated in Figure 3.18. For example, from Figure 3.18 the letter and digit of code F3 is interpreted as a product with a box-like shape.
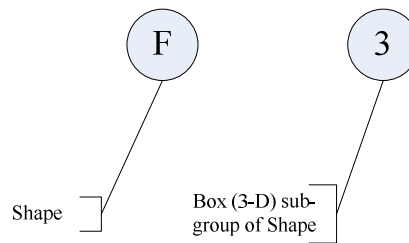
Figure 3.18: Interpretation of Product Shape code.

For the Material from which the product was made of, the number of level or sub-class of hierarchy is one. So, for this attribute letter M will represent the attribute and the sub-group in the hierarchy will be represented by a digit according to its position in the hierarchy. The coding structure for the Material attribute is illustrated in Figure 3.19. For example, from Figure 3.19 the letter and digit of code M1 are interpreted as a product made of metal.
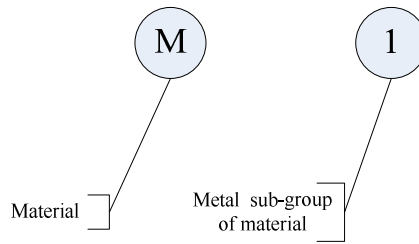
Figure 3.19: Interpretation of Material code.

The combination of all the attributes code that will be generated through data input into the CLD system by the customer will represent the customer/user configured product. The product code generated based on the examples in each of the attributes as explained above will be similar to what is shown below.

Figure 3.20: Example of Customer Generated Product code.

The meaning or interpretation of the above product code is explained thus -

A customer/user wants a product with a wheel that includes a drive system which could be used for outdoor sports purpose. The product should be able to move straight and turn in one direction only with the inner movement to be linear. The product will have an AC current with power rate between 700 watts to 1000 watts, be up to100 cm in length and to weigh between 50Kg to 100Kg with a box-like shape that is made of metal.

To arrive at the Coding Structure used, the following factors were considered;

   i.   The population of Attributes (application, motion, materials, shape, etc.)

  ii.   The detail the code should represent

 iii.   The code structure: chain-hierarchy type

 iv.   The letter representation (A, M, E, etc.) [77].
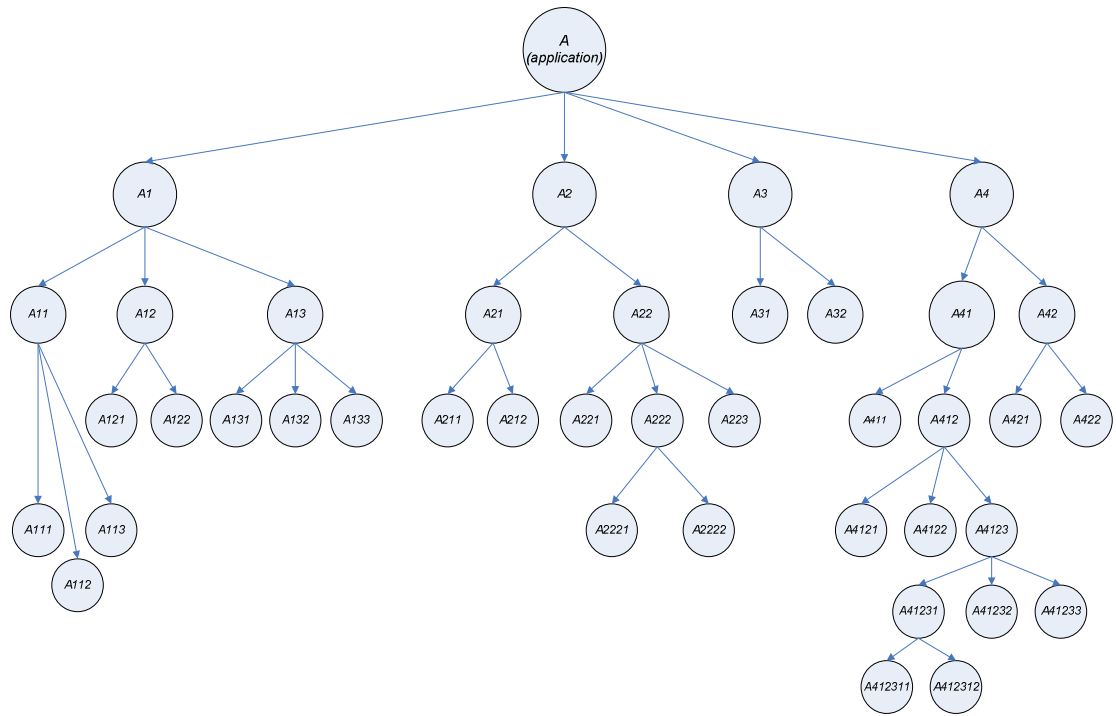
Figure 3.21: Coding structure for the Application Attribute
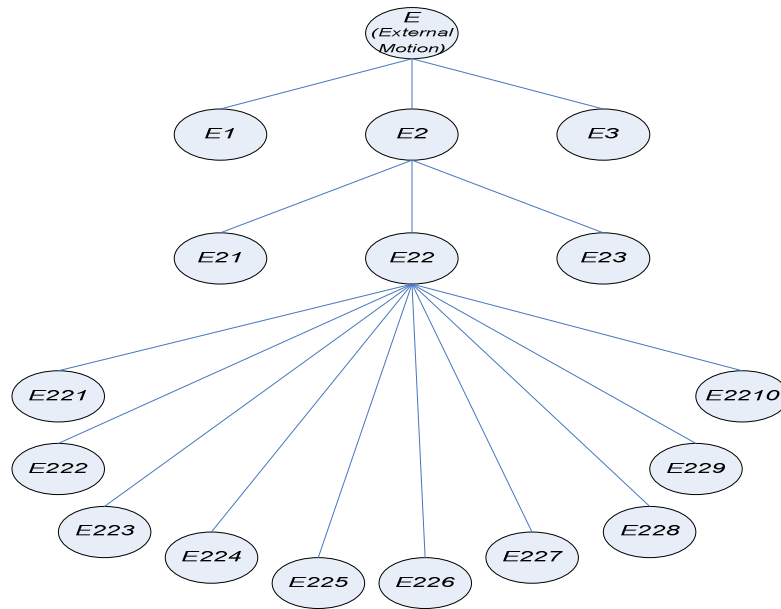
Figure 3.22: Coding structure for External Motion Attribute
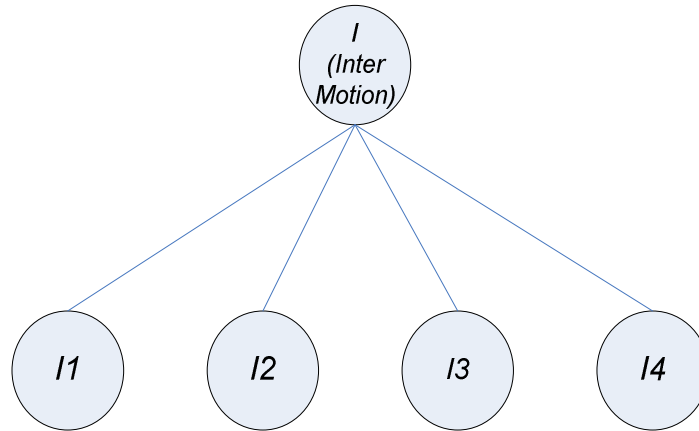
Figure 3.23: Coding structure for Internal Motion Attribute
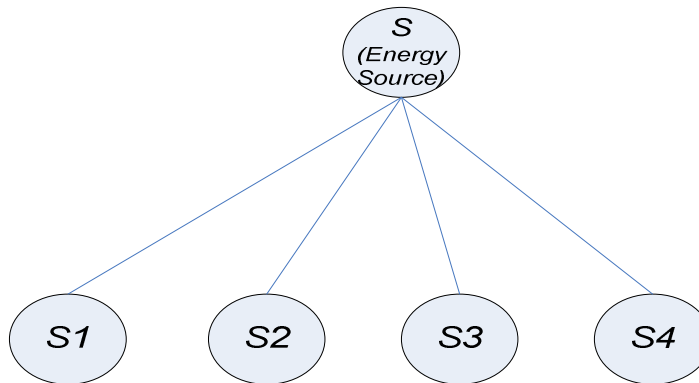
Figure 3.24: Coding structure for Energy Source Attribute
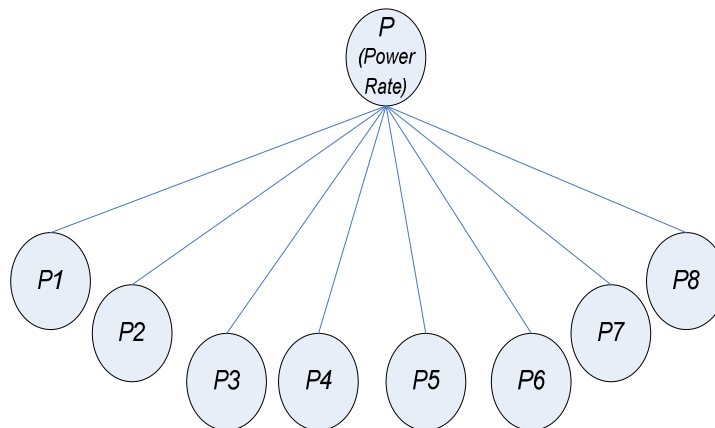
Figure 3.25: Coding structure for Power Rate Attribute
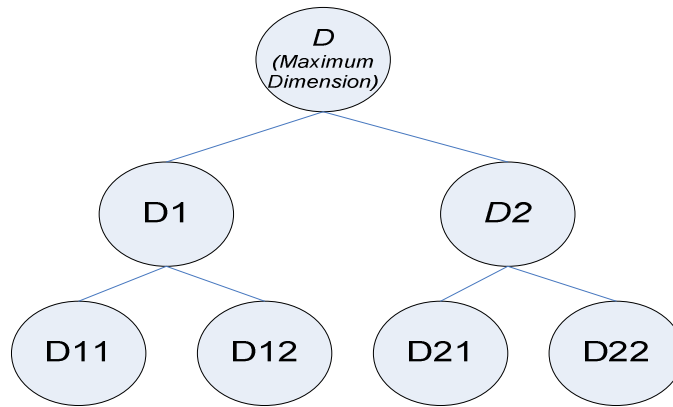
Figure 3.26: Coding structure for Maximum Dimension Attribute
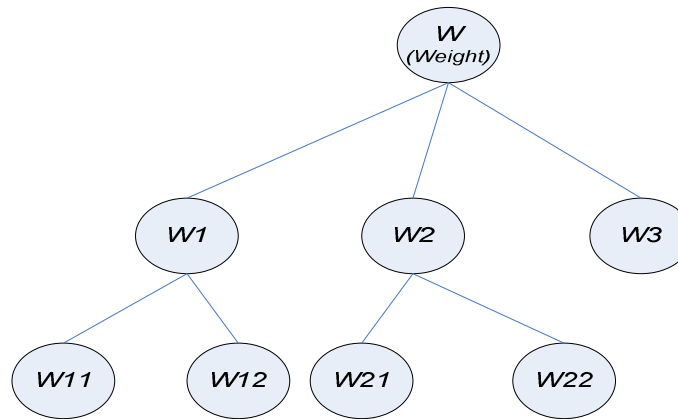
Figure 3.27: Coding structure for Weight Attribute
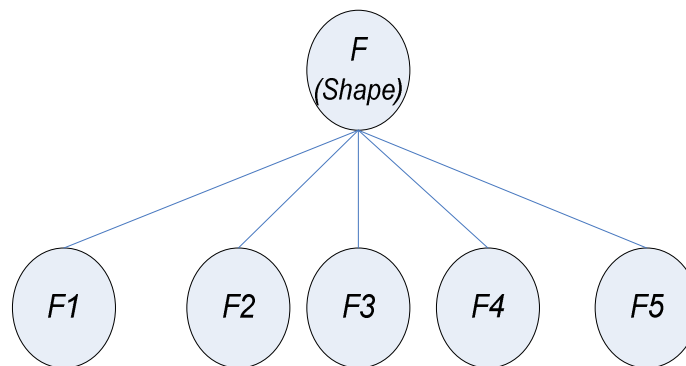
Figure 3.28: Coding structure for the Shape Attribute
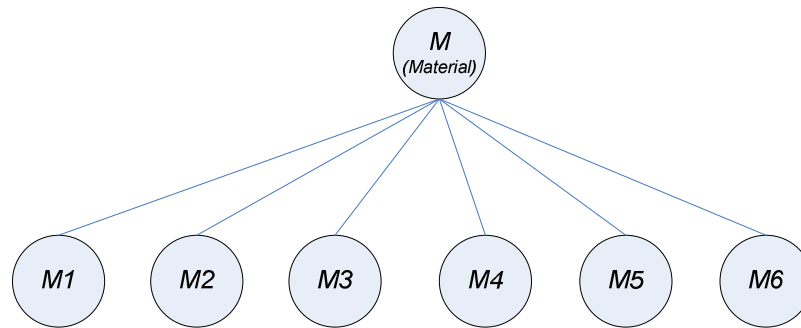
Figure 3.29: Coding structure for the Material Attribute

3.3.3 Products Database

The Products Database is a structured collection of all the customer/user goods and services such as products catalogues and inventories that are stored and organized in hierarchical order so that they can easily be accessed, managed, and updated.

In computing, databases are sometimes classified according to their organisational approach. The most common approach is the relational database, a tabular database in which data is defined so that it can be reorganised and accessed in a number of different ways. An object-oriented programming database is one that is congruent with the data defined in object classes and subclasses [79]. A distributed database is one that can be dispersed or replicated among different points in a network.

For this work, the object-oriented programming database was used because of its unique features of matching data that is defined in object classes and subclasses. The data will be modelled using the hierarchical model [80] in which data is organized into an inverted tree-like structure implying a multiple downward link in each node to describe the nesting, and a sort field to keep the records in a particular order in each same-level list. The structure arranges the various data elements in a hierarchy and helps to establish logical relationships among data elements of multiple products. Data elements in this model are well suited for one-to-many relationships with other data elements in the database.

The products information stored in the database will contain both the objects (the products) and their images so that when the product is sourced or retrieved from the database and displayed in the user graphic window, its image can also be seen.

The products stored in the database will be those from appliances attribute, sports attribute, tools attribute and the transports attribute and this is illustrated in Figure 3.30.
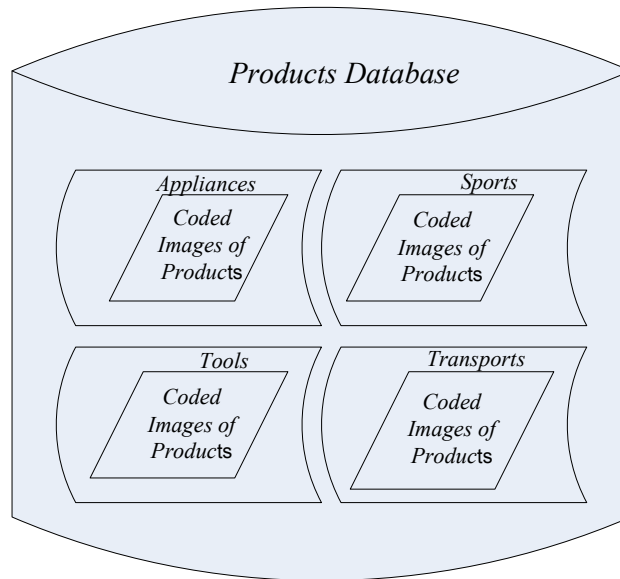
Figure 3.30: Product Database for CLD System.

3.3.4 Product Module Library

The Product Module library is more or less similar to the Products Database. This is a collection of all products components and module sub-assemblies of various products that is stored and organised in hierarchical order for easy accessibility, management and updates.

This is constructed to be a custom library of parts/components/module sub-assemblies and alternative parts/module sub-assemblies lists using a hierarchical structure. Users may then drag and drop parts/module sub-assemblies from the library [81] onto the modification side of the graphical users' interface (GUI) for product customisation or modification use.

The hierarchical structure [82] of the products library helps users to easily locate parts/sub-assemblies by assembly, part type, and any other categorisation. Projects may also be attached to a main products module library allowing automatic updates

to any of the selected product module library. The products module library may contain many different categories of sub-assemblies such as drive systems, wheels, seats etc as obtainable in bicycles.

The Products Module Library will be of two types:

(i). Individual Product Module Library - this will contain each product part/module sub-assembly as can be seen in Figure 3.30. That means every product will have a kind of mini-database for it components and this will be automatically updated in a systematic fashion.

(ii). General/Main Product Modula Library - this is the main products library that will cater for all the products module components and sub-assemblies. A typical example of the library is shown in Figure 3.31.

Another aspect of the product module library is that the general or main library will appear visible or be made available for the customer (the customer/user will have access to the library) during modification of the product(s).   The library (database) will be designed in such a way to allow the customer/user to drag part/module sub-assemblies from it onto the modification side of the Graphical User Interface (GUI), that is, the screen.

INDIVIDUAL PRODUCT MODULE LIBRARY (DATABASE)					
Product Component					
Part name	Part name	Part name	Part name	…	Part name
Part 1	Part a	Part x	Part z	…	Part k
⋮	⋮	⋮	⋮	⋮	⋮
Part n	Part n	Part n	Part n	…	Part n
Product module Sub-Assembly					
Part name	Part name	Part name	Part name	…	Part name
Part 1	Part a	Part x	Part z	…	Part k
⋮	⋮	⋮	⋮	⋮	⋮
Part n	Part n	Part n	Part n	…	Part n

Figure 3.31: Individual Product Module Library for CLD System.

GENERAL MODULE LIBRARY (DATABASE)					
Products Parts					
Part name	Part name	Part name	Part name	…	Part name
Part 1	Part a	Part x	Part z	…	Part k
⋮	⋮	⋮	⋮	⋮	⋮
Part n	Part n	Part n	Part n	…	Part n
Products module assembly					
Part name	Part name	Part name	Part name	…	Part name
Part 1	Part a	Part x	Part z	…	Part k
⋮	⋮	⋮	⋮	⋮	⋮
Part n	Part n	Part n	Part n	…	Part n
Other product parts					
Part name	Fasteners	Washers	bolts	…	n
Sizes					

Figure 3.32: General Products Module Library for CLD System.

3.4 The Analytic Hierarchy Process (AHP)

This is a structure technique that assists in dealing with complex decisions. Rather than prescribing a "correct" decision, the AHP helps to determine one. Without a structured technique, trying to evaluate the overall quality of different attributes of an application even in the CLD system would be very difficult [83]. After choosing the attributes, one has to determine how to compare each attribute with the other in terms of their importance, how to put a value on the information they carry in order to generate a meaningful result and how to interpret the results. A much better approach to quickly evaluate the attributes is an approach based on the use of Saaty's analytic hierarchy process (AHP) method that was developed to assist in multi-criteria decision-making problems.

In order to decide the total ranking [84] of the attributes of the hybrid classification system of PCS, the following procedures were undertaken:

(i). Problem Set-Up - The first step in the analytic hierarchy process is to set up the problem. This means the evaluation of the hybrid classification attributes. The nine attributes are compared based on their importance in the hybrid classification system for their evaluation.

(ii). Determine the Relative Weight of the Attributes to be Compared - After setting up the problem, the next step is to determine the relative weights of each of the comparison attributes. This is based on how important the attributes are relative to each other. For instance, Application may be more important in the overall function than energy source or vice versa or they may be equally important.

The analytic hierarchy process uses a pair-wise comparison technique. It works as follows: Starting with the attribute classifications which are application, external motion, internal motion, energy source, power rates, maximum dimension, weight, shape of the product and product material; a table structure as shown in Table 3.4 is created with m x m (9 x 9) matrices for the attributes classification.

(iii). Comparison of Relative Importance of Attributes to each other - the comparison is carried out using the following criteria:

Relative Importance	Value
Equal importance/quality	1
Somewhat more important/better	3
Definitely more important/better	5
Much more important/better	7
Extremely more important/better	9

Figure 3.33: criteria for Relative Importance of Attributes [83].

If an attribute falls between "equal importance" and "somewhat more important", then a value of 2 is assigned. The interpretation of this value is that the attribute is two times as important as the other attribute in the hybrid system. If it is between "somewhat more important" and "definitely more important", a value of 4 is assigned. Attribute between "definitely more important" and "much more important" attracts a value of 6 and finally, a value of 8 is assigned if the attribute is between "much more important" and "extremely more important".

The upper-left to lower-right diagonal elements of the table are comparing the relative importance of each attribute against itself. Using the values from the table in Figure 3.33, Table 3.4a shows that the attributes have the values of 1 because each attribute has equal importance compared to itself. By definition, all the upper-left to lower-right diagonal elements of an AHP comparison table will be 1. The upper-right cells of Table 3.4a of the AHP comparison table are filled with other values based on the relative importance values that were assigned to each attribute when compared with another. For instance, since application attribute is between somewhat more important" and "definitely more important" than external motion attribute, a value of 4 is assigned as can be seen in the table. That is, the for external motion attribute against application, the relative importance must be $\frac{1}{4}$ (0.25). The same procedure is applied to other attributes in generating the relative weight values for them. The results generated are shown in Table 3.4b and which weight factors are allocated is specified at the tail end of the table.

As for the ranking of alternatives [85], that is, the sub-groups of the attributes, the weight factors of their respective group or class are divided among them. For example, the application attribute has 46 as its value, this value is then divided among its hierarchy and the same is applicable to the rest of the attributes.

3.4.1 Mathematical Presentation of AHP

In order to calculate the AHP for the Products Chain System attributes for easy allocation of Weight Factors (WF), the following steps are followed:

Step 1: Compute column totals: $A = \left[a_{ij}\right]_{qxq}$

Where A is the matrix of components $\left[a_{ij}\right]$ and

qxq is the number of attributes in a column and row respectively.

Figure 3.33 is used to compute the column total. The matrix table is depicted in Table 3.4a.

Table 3.4a: AHP Comparison of Attributes Relative Weight Values.

	ATTRIBUTES								
	Applicati on	Ext. motio n	Int. motion	Energy source	Power rate	Max. dimensio n	Weight	Shape	Material
Application	1	4	4	7	5	5	5	4	4
Ext. motion	0.25	1	2	5	4	5	5	3	3
Int. motion	0.25	0.50	1	5	4	4	4	3	2
Energy source	0.17	0.21	0.18	1	2	4	4	3	3
Power rate	0.17	0.21	0.18	0.60	1	3	2	1	1
Max. dimension	0.20	0.21	0.18	0.40	0.40	1	0.25	0.33	0.33
Weight	0.20	0.21	0.27	0.40	0.40	4	1	1	1
Shape	0.25	0.36	0.36	0.40	1	4	1	1	1
Material	0.28	0.36	0.55	0.40	1	4	1	1	1
Total	2.78	7.14	9.09	20.00	20.00	33.33	25.00	16.67	16.67

Step 2: Divide each cell by its column total. The total column of each cell is shown in the last row of Table 3.4a. After the division, the result is indicated in Table 3.4b.

Table 3.4b: Result of AHP Comparison of Attributes Relative Weight Values.

	Application	Ext. motion	Int. motion	Energy source	Power rate	Max. dimension	Weight	Shape	Material
Application	0.36	0.54	0.44	0.34	0.27	0.16	0.21	0.21	0.23
Ext. motion	0.09	0.14	0.22	0.23	0.22	0.14	0.21	0.16	0.17
Int. motion	0.09	0.07	0.11	0.23	0.22	0.13	0.16	0.16	0.11
Energy source	0.06	0.03	0.02	0.05	0.09	0.11	0.17	0.17	0.19
Power rate	0.06	0.03	0.02	0.03	0.05	0.08	0.09	0.06	0.06
Max. dimension	0.07	0.03	0.02	0.02	0.02	0.03	0.01	0.02	0.02
Weight	0.07	0.03	0.03	0.02	0.02	0.11	0.04	0.06	0.06
Shape	0.09	0.05	0.04	0.02	0.05	0.11	0.04	0.06	0.06
Material	0.10	0.05	0.06	0.02	0.05	0.11	0.04	0.06	0.06

Step 3: Compute each row average using Table 3.4b.

$$\text{Weight or Priority Factor} = \frac{\text{Total Number of each row weight values}}{\text{number of attributes}}$$

The result is shown in Table 3.4c.

Table 3.4c: Priority Vector of the Attributes Relative Weight Values.

Attribute	Weight or priority factor
Application	**0.46**
Ext. motion	**0.12**
Int. motion	**0.08**
Energy source	**0.07**
Power rate	**0.05**
Max. dimension	**0.04**
Weight	**0.05**
Shape	**0.06**
Material	**0.07**

Weight Factor in %								
46	**12**	**8**	**7**	**5**	**4**	**5**	**6**	**7**
Application	**Ext. motion**	**Int. motion**	**Energy source**	**Power rate**	**Max. dimension**	**Weight**	**Shape**	**Material**

3.5 Conclusion

This chapter describes how the CLD is paramount in developing a system that will integrate the customer into a design system as a co-designer. It also highlights the approach used in the development of the CLD system. The approach presented can overcome some of the limitations of existing customer driven design systems. The approach showed the hybrid system of classification which will give the customer/user a wider choice of product features to select from using the various attributes inherent in the PCS of the hybrid system of classification structure. It also demonstrated the relevance of the Opitz Coding system in the design of a new coding structure by modifying the Opitz coding structure in order to come up with the structure or system that is suitable for the CLD system and showed the modification that was carried out. And finally, the Product Module library was also presented which showed how the products will be positioned in the library so that it will be easier for the customer/user to understand. The advantage of the library to the customer/user is that it is accessible to them during the modification process to drag components or sub-assemblies from it onto the product they want to modify unlike constraints present in other libraries or databases.

CHAPTER FOUR

ARCHITECTURE REPRESENTATION AND FRAMEWORK FOR DESIGN OF CLD SYSTEM

4.1 Introduction

Some approaches and methodology were developed for use to aid in the designing of the CLD system. This chapter is intended to merge these approaches together to develop and design the system algorithms and also demonstrate how the system will work in order to achieve its objectives.

This chapter first describes the template for the product chain structure of CLD. The template is used to generate the customer product code for the customer desired product. The methods for retrieval of similar product codes from the database are looked into as well, which consists of a search and sort method and the weight factor method. The reason for chosing WF method over search and sort is also stated.

The chapter also discusses the modification process for the retrieved product code and the stages involved in the modification. The modification stages involve four stages of customer interaction with the system before completing the modification process.

4.2 CLD System Framework

The basic structure on which the Customer-Led design system operates is based on gathering information from the customer/user of the system to generate a customised product code (i.e. candidate product code) from the products database for the customer needed product. The configuration of the CLD system consists of a customer/user terminal, product database, product similarity retrieval system, and customisation of the product. In this system, the customer/user can bring his/her idea of the type of product he/she wanted to reality through the product chain system of the customer-led design system.

In the basic structure, the customer/user interfaces with the product similarity retrieval system and product database by specifying processes on the customer/user terminal. The system application includes the following steps of processing as shown in figure 4.1 that summarises the system application flow:

- *Step 1:* The user will undergo an interactive section with the system by configuring data about his/her desired product. Here, product information is gathered/generated from the customer/user.

- *Step 2:* The product data inputted by the user into the system is used in generating a product code for his/her desired product. In this step, the product code generated is basically dependent on the customer/user configuration.

- *Step 3:* The Database is then searched for the match of the product code generated.

- *Step 4:* If a match is found then the product code is retrieved from the system to be display on the user interface (GUI) and then if the customer/user still wants to go ahead to customize some of the product features, he/she can proceed. However, if a match is not found in the database, no code will be retrieve and in this case the system will suggest a similar product code using the methodology for similarity retrieval system explained later in the chapter. The methodology will find similar product codes that may have resemblance in application and some other attributes to one that was requested by the customer/user. Then, step 3 (database is searched) is carried out again and if the user is satisfied, the product is displayed on the user terminal.

- *Step 5:* then, modification of the similar product is carried out to meet the customer/user required product.

In this manner, the user obtains the desired product from the system. Figure 4.1 shows the system application flow for the steps described above.
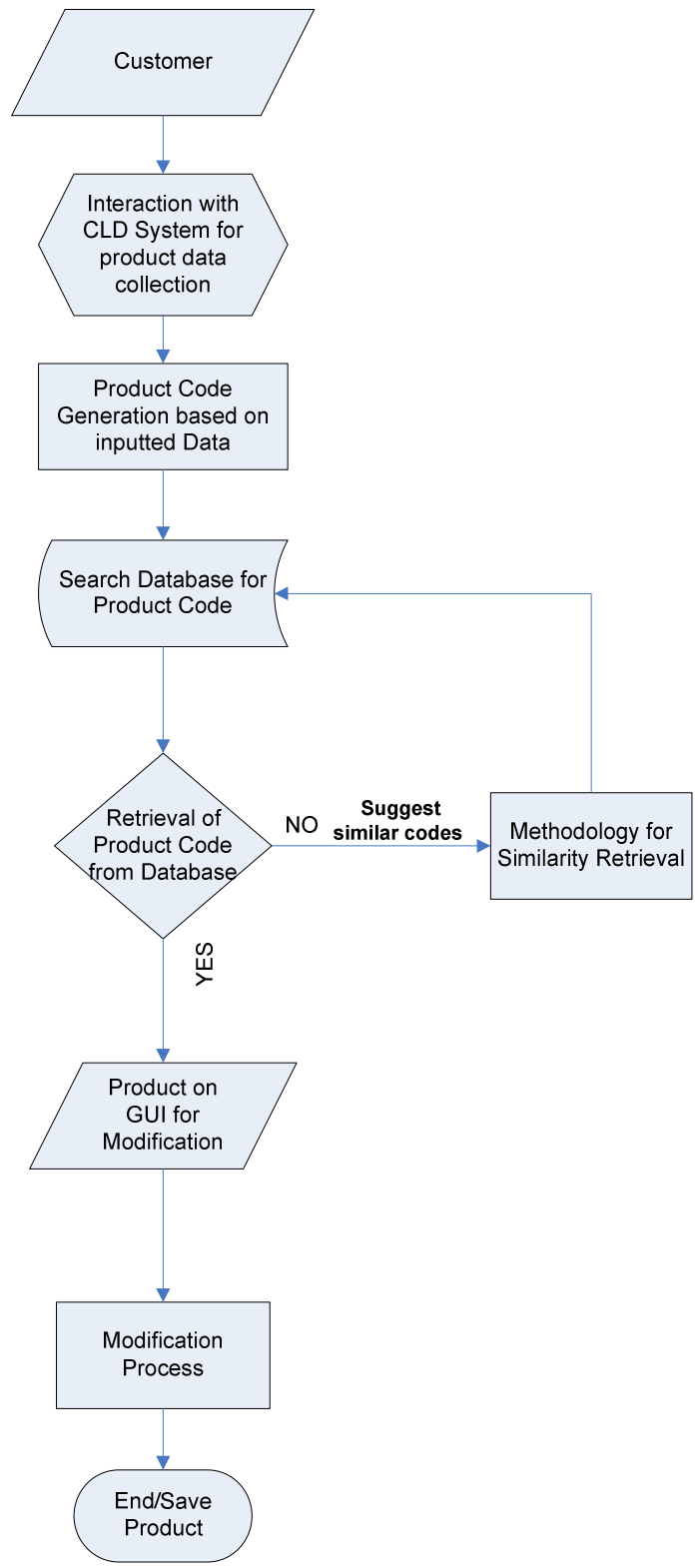
Figure 4.1: System Application Flow for the CLD System

4.3 Product Chain System of CLD Template

The Product Chain System architecture presented below uses the product hierarchy to show the detailed model of the customised products in the database, which will be used by the design engine for analysis, optimisation, and selection of appropriate products/components. To generate product codes and present or display the product from the user selections, a template is used that specifies a set of well defined guidelines and instructions, which guide the customer/user on how to go by and tell the design system in a structured manner how to perform the tasks [14]. The generic form of the Product Chain System template is shown in Table 4.1. The Product Chain System template shown below uses a top-down approach to define the family members. On the top of the hierarchy is the Product family, (*PF*), which comprises of different family attributes *(Pi)*. Each attribute is define based on their modules/components and their codes generated by analysing the components/modules in a hierarchical order. The Application attribute *(App)*, being the most important attribute of the product family is analysed using its modules/component in such a way that follows a decision tree-type to get the code for the application. The elements of *App* include – Appliances *(Apl)*, Sports *(Spo)*, Tools *(Tol)* and Transports *(Tra)*. From these elements, Sport *(Spo)* module- Indoor *(In D)* and Outdoor *(Out D)*, is chosen and then analysed to get to the next level. From the analyses, outdoor *(Out D)* is further analysed to generate wheel *(Whl)*, Sports trolleys *(Spo T),* and others sport products/equipments *(Oth)*. Also, wheel *(Whl)* which employed the attribute Option *(Whl Op)*, *x* and *y* is analysed. The *x* option represents wheels that are with drives *(WD)* while the *y* option represent wheels without drives *(WiD)* and the outcome of *Whl Op* is *x*. When the *App* code has been generated, it is then cross-referenced both vertically and horizontally with the other analysed product family attributes to generate the final product codes for the customer product. By cross referencing the Application attribute with other attributes, we have: For External Motion *(Ext M),* which has elements as Fixed (*Fi),* Moving *(Mo),* and Hand Held *(Hh)*. From this, moving *(Mo),* is selected to move to the next level if any. For Internal Motion *(Int M),* its elements consist of Linear *(Li),* Rotation *(Ro),* Reciprocation *(Re),* and Oscillation *(So).* From this element, *Li* is selected. For Energy Source *(Ene S),* the group has Manual *(Ma)*, Batteries *(Ba),* Electric Mains *(Em)* and Fuel *(Fu).* Out of these, *Ma* was selected. For the Power

Rates features we have the rate ranging from *≤100 to >2000.* And number zero (0) will stand for no rate where the *Ene S* is *Ma.* For Maximum Dimension *(Max D)*, we have minimum length *L(min)* and maximum length *L(max).* By selecting minimum length we generate *L(min).* The Weight *(Wei)* attribute has Light *(Lo),* Medium *(Me),* and Heavy *(Hy).* And *Lo* was selected from weight attributes. The product Shape *(Sha P)* attribute consist of Elongated *(1D),* Flat *(2D),* Box *(3D),* Rounded, *(Rd)* and Irregular *(Ir),* and from these, *2D* was selected. And finally, for the material attribute, Metal *(Me),* Ceramic *(Ce),* Elastomer *(El),* Composite *(Co)* and Wood *(Wo) are* its sub-group. And from this group, *Me* was selected.

At the lowest level of the hierarchy is the customer Selected Product *(SP)*, which represents the end result of the customer specific input to the template.

Table 4.1: Product Chain System Template Use in Selection of Appropriate Product.

_____

PF = {App, Ext M, Int M, Ene S, PoR, Max D, Wei, Sha P, Mat P}

App={Apl, Spo, Tol, Tra},

Ext M={Fi, Mo, Hh},

Int M={Li, Ro, Re, Os},

Ene S={Ma, Ba, Em, Fu},

PoR={≤100 - >2000},

Max D= {L(min.),L(max.)},

Wei= {Lo, Me, Hy},

Sha P= {1D, 2D, 3D, Rd, Ir},

Mat P= {Mt, Ce, El, Pl, Co, Wo}

Pi={(App, Ext M, Int M, Ene S, PoR, Max D, Wei, Sha P, Mat P)│App=(Apl, Spo, Tol, Tra)}

Spo= {In D, Out D},

Out D = {Whl, Spo T, Oth}

Whl Op= {x, y}

SP={(x={WD},Ext M={Fi, Mo, Hh},Int M={Li, Ro, Re, Os},Ene S={Ma, Ba, Em, Fu}, PoR={≤100 - >2000}, Max D={L(min.),L(max.)},Wei={Lo, Me, Hy},Sha P={1D, 2D,3D Rd, Ir},Mat P={Mt, Ce, El, Pl ,Co})}

SP={x={WD}, Ext M={Mo}, Int M={Li}, Ene S={Ma}, PoR={0}, Max D={L(min.)}, Wei={Lo}, Sha P={2D}, Mat P={Co})}

Where: *Ext M= external motion; Int M= internal motion; Ene S=energy source; PoR= power rates; Max D=maximum dimension; Wei=weight; Sha P=shape of product; Mat P=product materials;*

Mo=moving; Li=linear; Ma=manual; L(min.)=minimum length; Lo=Light; 2D=two dimensional; Co=composite.

_____

4.4. Methodology for Retrieval of Similar Product Codes

The objective of the problem at hand is to suggest similar product codes from the product database of the design system, which are similar to the customer request code due to the fact that the initial customer configuration input into the design system is unable to bring out an exact product code. Three methodologies have been developed for the above. The first method is Search by code similarity (search and sort procedure), second is Similarity based on Weight Factor and the third is Automatic generation of a similarity index using Artificial Neural Networks (ANN).

4.4.1. Search by Code Similarity

This is a search and sort procedure and consists of two steps. Each of the steps is explained below.

Step 1: *Search Procedure Using the Application Attribute of the Product Chain System*

This is a search and retrieval procedure that acquires search intent information from the customer/ user and identifies a set of potentially useful similar product codes. The procedure uses the Application Attribute structure of the Product Chain System to provide attributes (each corresponding to a specific product characteristic) with respect to which the user specifies the search intent from the inputted configuration. This uses the first digit of the Application attribute in the customer/user initial product code to search and retrieve similar product codes from the database. The procedure retrieves products codes that satisfy this similarity level when compared to the specified/ requested product.

Step 2: *Sorting Procedure Using Second Digits of Application Attribute*

This step involves using the second digits of the application attribute in the customer/user product code to further narrow or sort the product codes generated from step 1 above in order to generate closely similar product codes to the customer-specified product.

Here, the result (product codes) from the first step is narrowed down to display only the product codes that are closely similar to the customer/user configured product code by applying the second digits of the application attribute.

However, this method was later discovered not to be suitable for the intent of this work. The reason was that the application attribute may not be the best option to be included in suggesting for similar products because of its sub-class attributes in that, a similar product might be in a different sub-class and if application is then applied the very similar product may not be suggested. For example, a bicycle may belong to two sub-classes of application; sports and transportation. Using the application attribute might miss the generation of a similar product.

4.4.2. Similarity based on Weight Factor

In this method, Weight Factor (WF) is assigned to the attributes based on their importance in the PCS. The WF used is summed up to 100% which is distributed to the attributes as shown in table 4.2 below. This is done using a structural technique called Analytic Hierarchy Process (AHP) [86] which was explained in the previous chapter. It is used to structure and determine the WF value assigned for the ranking of the attributes. Also, each of these values is share among the sub-groups of each attribute (*note: the calculation and steps taken to arrive at the WF value has been explained in the previous chapter).* For instance, Application with 46% shares it among its sub-groups based on hierarchy levels as shown in figure 4.1 below (the WF value is shown in the bracket in the attribute). The same thing is applicable to other attributes based on the number of hierarchy levels they have. With this method, the weighted factor (WF) of the attributes for each product is summed up and the database displays the product codes in the user graphic based on their ranking. The higher the WF value, the more similar the product code is to the customer requested product. And one good thing about this is that the customer/user can indicate the level of similarity he/she wants based on the similarity index.
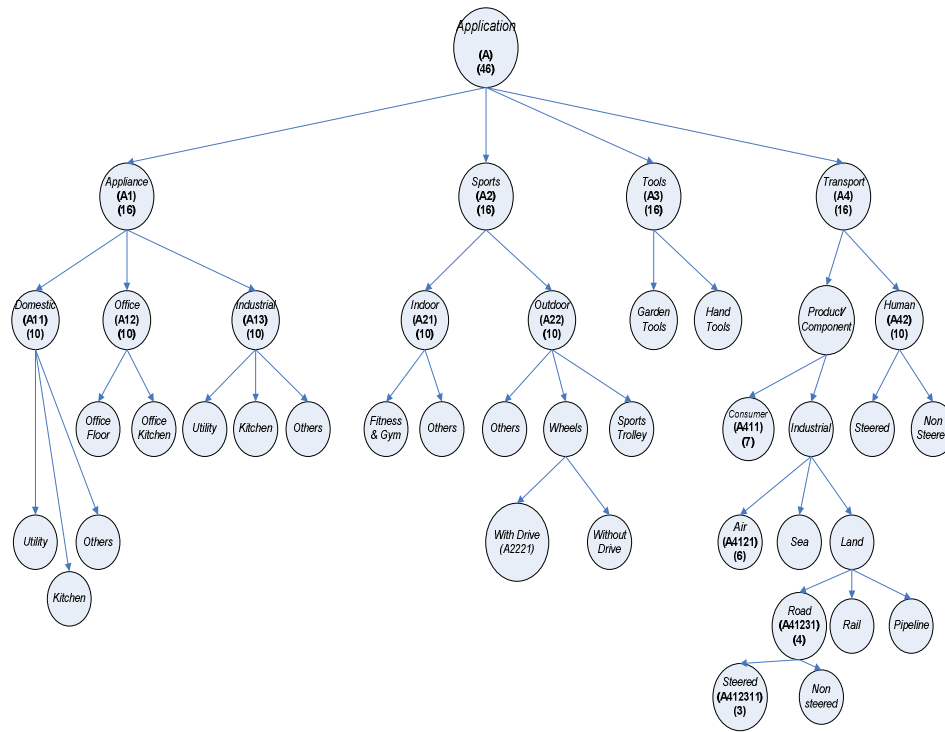
Figure 4.2: Weight Factor Allocation for Application Attribute

Table 4.2: Weight Factor for PCS Attributes

Attribute	Weight Factor (WF)	Distribution Of WF In Hierarchy Sub-Group/Level					
		1	2	3	4	5	6
Application	46	16	10	7	6	4	3
Ext. Motion	12	8	4	-	-	-	-
Int. Motion	8	8	-	-	-	-	-
Energy Source	7	7	-	-	-	-	-
Power Rate	5	5	-	-	-	-	-
Max. Dimension	4	3	1	-	-	-	-
Weight	5	3	2	-	-	-	-
Shape	6	6	-	-	-	-	-
Materials	7	7	-	-	-	-	-

4.4.2. Automatic generation of similarity index using Artificial Neural Network (ANN).

This method was developed to cater for the lapses in the first two methods. The concept is explained in chapter five under test and validation.

4.5. Customer Product Code Generation

This section presents the steps followed in order to generate the product code from the customer/user based on the weight factor. This method has the ability to generate product codes that are closely similar to the candidate product code no matter which hierarchy or sub hierarchy the product belongs to.

In generating the product code for a customer/user request and to determine if the code generated is actually what the customer wants, a two step process is used to optimise the model of the product chain system template.

Step 1: Gather code from user's specification/ configuration.

In order to gather the product request code from the customer/user, the Product Chain System template in table 4.1 above could be utilised. If a feasible solution is achieved in this step, then step 2 is of no importance.

Step 2: Find the closest product code in the Hierarchical database.

If the first step does not yield a feasible solution, the design system will try to find similar product codes to that generated initially. This is done through the Product Similarity Retrieval System from the product database by using the parameters inputted by the customer/user when configuring the initial product request.

In order to examine the practicability of the system steps, the following test was conducted.

TEST:

Assuming the customer/user initial (requested) product code (the generation of the code is explained in section 5.3.1) is:

A222100 E22 I2 S1 P0 D21 W11 F2 M5

This represents a Bicycle, and from the database, there is no feasible product that matches the product code as can be seen in table 4.3 which illustrates all the products codes in the database. Then, by finding the closest product code, we apply step 2 to generate a similar product code to the candidate code.

In order to generate a similar product code, the following procedures are followed:

(1). The system allocates WF to the customer configured or generated product code: the customer/user product code is assigned WF values based on their group or sub group within the attributes and must total 100%. That is, the product code gathered from the customer configuration data has 100% WF value (see table 4.2);

A222100 (46) **E22** (12) **I2** (8) **S1** (7) **P0** (5) **D21** (4) **W11** (5) **F2** (6) **M5** (7)

(2). Generate WF values for all the product codes in the product database: This is done by ascribing WF values to each attribute of the product codes and the value for each attribute is dependent on their hierarchy level/sub-group as contain in table 4.2 above. Here, each attribute code which is based on their position in the hierarchy is compared with each attribute of the customer configured product code. If there is a 100 percent match then the system allocates the same WF value which is in the configured product code to the product code in the database and if differs, the system will allocate a WF value based on the position where the other code differs from the configured product code. Table 4.4 shows the Calculation of the Weight Factor for each Attribute. For instance, if a product code is such as the one below:

A222200 E22 I2 S1 P0 D21 W11 F2 M5

Its attributes will be compared to that of the configured product code. For this case, since their first three hierarchy sub-groups are the same, the code will have its first three WF values to be the same with the configured product code that is, 1st sub-group will have 16, 2nd will be 10 and third to be 7 (refer to table 4.2 for each sub-group WF value). Then the other sub groups that are not the same will have WF value to be zero (0). Therefore, for this attribute its WF value will be the addition of 16, 10 and 7 which equals 33 (i.e. A222200 (33)). For the external motion, it has two sub-groups which are the same as those of the configured product code. So from table 4.2, 1st sub-group WF value is 8 and the 2nd is 4, therefore, the total WF value for this is 12 (i.e. E22 (12)) which is 100 percent WF value for external motion. The

internal motion has one sub-group and from table 4.2, the WF value is 8 (i.e. I2 (8)) which is the same as the configured code. The other attributes from energy source to product material have the hierarchy sub-group and therefore will have the same WF value with the configured product code. Which means that the energy source will have the same WF value of 7 (i.e. S1 (7)), power rate WF value of 5 (i.e. P0 (5)), maximum dimension WF value of 3 and 1 which is 4 (i.e. D21 (4), weight WF value of 3 and 2 which is 5 (i.e. W11 (5)), product shape WF value of 6 (i.e. F2 (6)), and the material attribute WF value of 7 (i.e. M5 (7)) with the configured product code. This can be seen in table 4.4, which shows the calculation of WF values for the entire product code in the database. (*Note:* if one digit of the attribute of the product code in the database does not match the first digit of the configured or candidate product code, then the WF value for such attribute is zero (0)).

(3).Ranking of the Product codes: After allocating the WF values to the codes, the system automatically ranks the product codes according to their WF values with the highest value on top. This is illustrated in table 4.5. The higher the WF value, the closer/similar the product code is to the configured or candidate code gathered from the customer.

Table 4.4 shows the calculation of the WF value for each attributes and the total WF value for the product in the database, while table 4.5 illustrates the ranking of the product codes from the highest to the lowest. From table 4.5 it can be deduced that the closer product codes to the candidate (customer configured product) one are the codes with WF between 52%- 87% similarity indexes. And this could be suggested as similar product codes to the customer based on his/her configured data.

Also, the same test was carried out on all other products in the database using different customer configured product codes. And when the Weight Factor method was also applied to the products in the database in comparison to the customer candidate product code as it was done in the previous test, the ranking of the product codes generated based on their similarity indexes which shows how close the products were to the candidate code for each product in the database are shown in tables 4.6 - 4.25. The customer configured product code used to generate the ranking of the Database Product codes Based on the WF Calculation table are shown on top of each table.

Table 4.3: Product Codes Database

Application	External Motion	Internal Motion	Energy Source	Power Rate	Maximum Dimension	Weight	Shape	Material	Product Database
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle
A211000	E10	I2	S1	P0	D21	W11	F5	M5	Exercise Bike
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle
A111000	E10	I2	S3	P8	D12	W12	F3	M4	Dryer
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift

Table 4.4: Calculation of the Weight Factor for each Attributes

Application	External Motion	Internal Motion	Energy Source	Power Rate	Maximum Dimension	Weight	Shape	Material	Product Database
A421000(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F2(6)	M5(7)	Bicycle(54)
A211000(16)	E10 (-)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F5(-)	M5(7)	Exercise Bike(52)
A310000 (-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F5(-)	M1(-)	Wheel Barrow(41)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W21(-)	F2(6)	M1(-)	Pallet Truck(42)
A113000(-)	E21(8)	I4(-)	S3(-)	P1(-)	D11(-)	W11(5)	F3(-)	M4(-)	Table Fan(13)
A310000(-)	E22(12)	I2(8)	S3(-)	P5(-)	D12(-)	W11(5)	F5(-)	M1(-)	Lawn Mower(25)
A211000(16)	E10(-)	I1(-)	S3(-)	P2(-)	D22(3)	W12(3)	F5(-)	M5(7)	Tread Mill(29)
A222200(33)	E22(12)	I2(8)	S1(7)	P0(5)	D11(-)	W11(5)	F2(6)	M6(-)	Skate Board(76)
A223000(26)	E22(12)	I2(8)	S1(7)	P0(5)	D22(3)	W12(3)	F2(6)	M1(-)	Trolley(70)
A222200(33)	E22(12)	I2(8)	S1(7)	P0(5)	D12(-)	W11(5)	F2(6)	M5(7)	Scooter(83)
A112000(-)	E10(-)	I3(-)	S3(-)	P3(-)	D11(-)	W11(5)	F3(-)	M4(-)	Blender(5)
A121000(-)	E30(-)	I3(-)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Stapler(17)
A112000(-)	E30(-)	I2(8)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Can Opener(25)
A320000(-)	E30(-)	I1(-)	S3(-)	P5(-)	D12(-)	W11(5)	F3(-)	M1(-)	Chain Saw(5)
A222200(33)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F2(6)	M5(7)	Unicycle(87)
A111000(-)	E10(-)	I2(8)	S3(-)	P8(-)	D12(-)	W12(3)	F3(-)	M4(-)	Dryer(11)
A320000(-)	E30(-)	I1(-)	S1(7)	P0(5)	D11(-)	W11(5)	F2(6)	M1(-)	Scrapper(23)
A113000(-)	E30(-)	I1(-)	S3(-)	P6(-)	D11(-)	W11(5)	F3(-)	M5(7)	Pressing Iron(12)
A310000(-)	E30(-)	I2(8)	S3(-)	P5(-)	D12(-)	W11(5)	F3(-)	M1(-)	Blower Vac(13)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F2(6)	M1(-)	Hand Truck(47)
A121000(-)	E30(-)	I3(-)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Stapler(17)
A133000(-)	E30(-)	I3(-)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Stapler(17)
A133000(-)	E21(8)	I4(-)	S3(-)	P1(-)	D11(-)	W11(5)	F3(-)	M4(-)	Table Fan(13)
A113000(-)	E21(8)	I4(-)	S3(-)	P1(-)	D11(-)	W11(5)	F3(-)	M4(-)	Table Fan(13)
A113000(-)	E22(12)	I3(-)	S3(-)	P4(-)	D11(-)	W11(5)	F5(-)	M4(-)	Vacuum Cleaner(17)
A122000(-)	E30(-)	I2(8)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Can Opener(25)
A211000(16)	E10(-)	I3(-)	S1(7)	P0(5)	D12(-)	W11(5)	F5(-)	M5(7)	Stepper(40)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W21(-)	F2(6)	M1(-)	Pallet Stacker(42)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W21(-)	F3(-)	M1(-)	Safe lift(36)

Table 4.5: Ranking Of the Database Product codes Based on the WF Calculation

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	87
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	83
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	76
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	70
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	54
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	47
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	42
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	42
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	41
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	40
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	40
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	36
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	29
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	25
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	25
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	25
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	23
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	17
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	13
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	12
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	11
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	5
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	5
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	5
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	5
A112000	E1	I3	S3	P3	D11	W11	F3	M4	Blender	5

Table 4.6: Ranking Of the Database Product codes Based on the WF Calculation for Dish Washer

A111000 E10 I2 S3 P6 D12 W12 F3 M1 → DISH WASHER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	78
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	53
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	53
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	50
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	45
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	45
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	43
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	39
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	35
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	35
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	35
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	35
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	29
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	27
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	26
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	21
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	20
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	20
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	18
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	18
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	17
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	15
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	15
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	14
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	13
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	11
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	11
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	11

Table 4.7: Ranking Of the Database Product codes Based on the WF Calculation for Scooter

A222200 E22 I2 S1 P0 D12 W11 F2 M5 → SCOOTER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	96
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	92
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	83
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	67
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	50
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	44
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	43
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	38
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	38
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	37
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	36
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	32
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	29
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	28
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	28
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	26
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	26
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	20
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	20
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	20
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	20
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	17
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	16
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	16
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	16
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	15
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	15
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	9
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	8

Table 4.8: Ranking Of the Database Product codes Based on the WF Calculation for Blender

A112000 E10 I3 S3 P3 D11 W11 F3 M4 → BLENDER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	61
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	57
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	57
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	55
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	49
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	48
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	45
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	45
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	39
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	39
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	31
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	28
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	24
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	22
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	21
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	21
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	15
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	9
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	9
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	8
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	6
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	5
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	5
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	5
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	5
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	5
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	3
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	0
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	0

Table 4.9: Ranking Of the Database Product codes Based on the WF Calculation for Can Opener

A112000 E30 I2 S1 P0 D11 W11 F3 M1 → CAN OPENER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	72
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	70
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	62
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	62
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	61
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	53
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	53
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	41
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	41
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	40
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	35
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	33
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	33
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	32
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	32
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	31
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	31
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	30
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	29
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	28
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	27
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	27
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	25
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	25
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	25
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	23
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	20
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	13
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	20

Table 4.10: Ranking Of the Database Product codes Based on the WF Calculation for Pallet Truck

A412311 E22 I2 S1 P0 D21 W21 F2 M5 → PALLET TRUCK

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	93
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	88
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	87
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	65
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	49
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	49
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	45
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	42
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	38
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	36
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	20
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	20
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	20
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	19
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	18
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	15
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	12
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	12
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	12
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	12
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	10
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	8
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	8
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	7
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	0
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	0

Table 4.11: Ranking Of the Database Product codes Based on the WF Calculation for Stapler

A113000 E30 I3 S1 P0 D11 W11 F3 M1 → STAPLER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	73
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	72
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	70
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	70
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	63
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	62
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	61
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	49
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	45
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	40
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	33
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	33
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	31
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	31
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	28
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	25
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	24
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	24
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	22
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	21
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	20
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	19
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	19
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	17
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	17
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	17
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	15
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	5
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	3

Table 4.12: Ranking Of the Database Product codes Based on the WF Calculation for Lawn Mower

A310000 E22 I2 S3 P5 D12 W11 F5 M1 → LAWN MOWER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	84
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	82
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	44
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	33
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	32
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	32
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	30
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	29
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	29
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	29
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	27
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	27
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	27
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	26
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	25
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	25
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	25
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	23
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	23
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	23
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	23
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	62
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	16
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	15
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	15
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	15
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	15
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	15
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	15

Table 4.13: Ranking Of the Database Product codes Based on the WF Calculation for Stepper

A211000 E10 I3 S1 P0 D12 W11 F5 M5 → STEPPER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	76
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	74
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	44
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	40
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	40
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	36
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	31
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	28
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	28
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	28
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	28
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	24
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	23
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	22
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	20
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	20
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	20
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	19
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	17
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	15
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	12
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	12
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	12
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	9
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	9
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8

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Table 4.14: Ranking Of the Database Product codes Based on the WF Calculation for Vacuum Cleaner

A113000 E22 I3 S3 P4 D11 W11 F5 M4 → VACUUM CLEANER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	77
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	63
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	62
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	57
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	47
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	47
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	39
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	35
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	33
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	33
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	33
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	25
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	23
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	22
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	21
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	20
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	18
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	17
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	17
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	17
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	17
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	16
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	15
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	15
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	15
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	12
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	12
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	12
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	9

Table 4.15: Ranking Of the Database Product codes Based on the WF Calculation for Safe lift

A412311 E22 I2 S1 P0 D21 W21 F3 M1 → SAFE LIFT

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	94
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	94
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	89
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	43
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	42
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	36
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	36
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	36
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	33
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	33
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	32
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	32
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	27
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	25
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	25
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	25
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	21
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	21
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	19
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	45
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	14
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	14
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	13
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	12
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	12
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	12
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	6
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	6
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	3

Table 4.16: Ranking Of the Database Product codes Based on the WF Calculation for Pressing Iron

A113000 E30 I1 S3 P6 D11 W11 F3 M5 → PRESSING IRON

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	73
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	68
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	62
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	53
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	48
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	45
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	43
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	43
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	43
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	41
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	38
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	38
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	33
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	29
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	25
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	19
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	15
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	15
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	15
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	12
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	12
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	12
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	9
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	6
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	5
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	5
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	3
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	0
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	0

Table 4.17: Ranking Of the Database Product codes Based on the WF Calculation for Table Fan

A113000 E21 I4   S3 P1 D11 W11 F3 M4 → TABLE FAN

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	77
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	70
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	70
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	68
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	61
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	48
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	47
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	41
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	31
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	31
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	31
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	23
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	21
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	21
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	17
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	17
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	17
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	14
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	13
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	13
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	13
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	13
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	13
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	11
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	10
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	13
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	8
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	8
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	8

Table 4.18: Ranking Of the Database Product codes Based on the WF Calculation for Blow Vac

A310000 E30 I2 S3 P5 D12 W11 F3 M1 → BLOWER VAC

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	82
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	66
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	62
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	43
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	41
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	41
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	35
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	33
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	33
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	33
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	33
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	21
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	21
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	21
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	21
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	21
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	20
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	20
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	18
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	17
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	16
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	15
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	15
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	13
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	13
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	13
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	10
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	9

Table 4.19: Ranking Of the Database Product codes Based on the WF Calculation for Washing Machine

A111000 E10 I2 S3 P3 D12 W12 F3 M1 → WASHING MACHINE

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	95
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	62
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	53
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	45
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	45
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	45
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	43
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	39
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	35
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	35
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	35
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	35
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	35
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	30
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	29
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	27
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	24
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	21
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	20
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	19
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	18
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	18
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	15
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	14
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	13
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	11
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	11
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	11

Table 4.20: Ranking Of the Database Product codes Based on the WF Calculation for Crane

A412312 E22 I2 S2 P3 D21 W30 F5 M1 → CRANE

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	74
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	74
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	74
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	74
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	37
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	33
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	30
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	24
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	24
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	24
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	20
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	20
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	18
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	18
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	15
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	15
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	15
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	15
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	9
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	8
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	7
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	7
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	7
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	7
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	7
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	6
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	5
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	0

Table 4.21: Ranking Of the Database Product codes Based on the WF Calculation for Stapler

A121000 E30 I3 S1 P0 D11 W11 F3 M1 → STAPLER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	70
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	70
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	62
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	62
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	61
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	43
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	40
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	39
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	35
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	33
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	33
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	33
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	31
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	31
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	28
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	25
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	24
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	24
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	22
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	21
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	20
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	19
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	19
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	17
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	17
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	17
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	5
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	3

Table 4.22: Ranking Of the Database Product codes Based on the WF Calculation for Exercise Bike

A211000 E10 I2 S3 P1 D21 W11 F5 M5 → EXERCISE BIKE

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	84
A211000	E22	I2	S1	P0	D12	W11	F5	M5	Stepper	76
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	40
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	40
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	44
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	30
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	30
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	29
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	26
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	24
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	24
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	23
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	20
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	19
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	18
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	17
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	17
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	17
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	17
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	13
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	13
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	12
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	12
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	12
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	12
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	5
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	5
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	5
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	5

Table 4.23: Ranking Of the Database Product codes Based on the WF Calculation for Scrapper

A320000 E30 I1 S1 P0 D11 W11 F2 M1 → SCRAPPER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	89
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	43
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	40
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	40
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	40
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	40
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	40
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	40
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	40
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	30
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	29
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	28
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	27
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	26
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	25
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	25
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	23
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	23
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	23
A211000	E22	I2	S1	P0	D12	W11	F5	M5	Stepper	20
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	19
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	13
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	11
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	9
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	9
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	9
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	9
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	9
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	5

Table 4.24: Ranking Of the Database Product codes Based on the WF Calculation for Cloth Dryer

A111000 E10 I2 S3 P8 D12 W12 F3 M1 →CLOTH DRYER

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	57
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	53
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	45
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	45
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	45
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	43
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	39
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	35
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	35
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	35
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	35
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	35
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	30
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	29
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	27
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	24
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	25
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	20
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	19
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	18
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	18
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	15
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	15
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	14
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	13
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	11
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	11
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	11

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Table 4.25: Ranking Of the Database Product codes Based on the WF Calculation for Unicycle

A222200 E22 I2 S1 P0 D21 W11 F2 M5 → UNICYCLE

APPLICATION	MOTION-EXTERNAL	MOTION-INTERNAL	ENERGY SOURCE	POWER RATE	MAXIMUM DIMENSION	WEIGHT	SHAPE	MATERIAL	DATABASE PRODUCT	SIMILARITY INDEX (%)
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	96
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	89
A222100	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	87
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	70
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	54
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	47
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	42
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	42
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	41
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	40
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	40
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	36
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	29
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	25
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	25
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	25
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	23
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	17
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	13
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	13
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	13
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	13
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	12
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	11
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	5
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender	5

4.6. Modification Process for the Retrieved Product Code

After retrieving the product that is similar or closely matched to the intended product from the database, the next step for the user/customer is to modify the selected product in order to match more accurately the customer configured product.

The modification process is a complex procedure because it analyses the internal structure of the product parts for modification. This involves the product assembly and sub-assembly structures which includes the hierarchical relationships between the product parts or sub-assemblies and mating conditions, the product module library, and product link structure. The process for modification is divided into two sections. The first section is called customer/user interaction and the second section is referred to as the internal system execution. The two sections will run concurrently during the modification process.

There are three stages for the product modification for the customer retrieved product:

- *Stage 1: Selection of the Product for modification.*
- *Stage 2:Displaying of the Parameters that define the product*
- *Stage 3: User input parameters for modification*

4.6.1. Customer Interaction Section

This section is where the customer/user performs all the modifications or customisation that is to be done on the product. The customer/user can carry out whatever trial and error operations he/she wants to perform and can also manipulate any part or module sub-assembly of the product. The customers will interact with the system using a mouse and keyboard.

4.6.2. Product Internal Structure of the System

All information contained in this section is executed behind the screen, that is, in the central processing unit of the system. This section solely depends on the first section because it is what is inputted into the system that is acted upon.

The content of the system internal structure of the product includes:

i. Product assembly model structure: (a) hierarchical relationship, (b) mating condition and attachment type structure and (c) product link structure

ii. Product module or part library

iii. General module library

iv. Product assembly and disassembly process

In the system's internal structure of the product, the majority of the information here is not accessible by the customer/user. The only exemption here is the general module library and product module/part library. The reason why these two are available to the user is because during the modification process (where the customer executes or effects the changes on the product), he/she will need the part library to modify the product.

4.7 Product Modification stages

This section deals with the explanation of stages involved in modifying a product in the CLD system. As was earlier mentioned above, the modification process is a three stage process. Before any stages are executed, the task to be done in each of the stages by the customer/user will be specified on the screen at the start of the modification process for each of the stages. In the modification stages, the stages are interactive in which a task to be performed by the user/customer is specified and the customer will respond by either choosing from the options or input what he/she wants to do at that level.

4.7.1. Stage 1: Selection of the Product for Modification

This is the first step in the stages involved in the product modification and it is divided into two tasks:

TASK A: Here, the similar retrieved products are displayed with products code name, SI values and the pictorial view of each of the products in the user graphic interface according to their closeness to the candidate product. The products are arranged with the highest SI value on top while the product with least SI value will be at the bottom of the ranking. The user selects the product that is more closely

matched or similar to his/her configured product from the list of products displayed on the screen based on the SI value by ticking the appropriate box beside the product chosen. Task A of stage 1 on the GUI screen will resemble the model shown in Figure 4.3.

TASK B: this task consists of three steps. After the customer/user has selected a product to be modified from Figure 4.3, the system automatically carries out Step 1 as soon as Task B is completed without any interference from the customer/user. This involves checking the selected product to find out in terms of motion if the selected product has the same motion orientation or specification with the candidate product. If it does, the "Compatible" box will be highlighted and the modification process will proceed to the next stage. But if it does not have the same motion specification, the "Not compatible" box will be highlighted and an error text will be shown in a text box (in red, as shown in figure 4.4); "one of the product chain system attributes of the candidate product code is not motion compatible with the selected product".

This is followed by Step 2 which has two options buttons - "AMEND" or "IGNORE". The customer has to select one of the options. If the "IGNORE" button is selected, then the system proceeds to the next stage of modification. But if the "AMEND" button is selected, the system activates the next step.

In Step 3, the system will prompt the customer/user to select from the drop-down menu the type of motion to be given to the selected product. The customer, placing the cursor on any of the parameters of the drop-down menu will find the description of each parameter (motion type). After the selection has been made, the system proceeds to the next modification stage.

Task B of stage 1 on the GUI screen will resemble the model shown in Figure 4.4.

STAGE 1: Product for modification is selected.

Task A: Check the result produced by the retrieval system and the Artificial Neural Network to choose the product that is very similar to the desired one based on the Similarity index value (SI).

Product Code Name	SI Value (%)	Pictorial View
☐ A	87	Picture of A
☐ B	83	Picture of B
☐ C	71	Picture of C
☐ D	68	Picture of D
☐ E	64	Picture of E
☐ F	61	Picture of F
☐ G	59	Picture of G
☐ H	35	Picture of H
☐ I	23	Picture of I
☐ K	9	Picture of K

Figure 4.3: Model of the Selection of Product for Modification Process.

Task B: Product Compatibility Check.
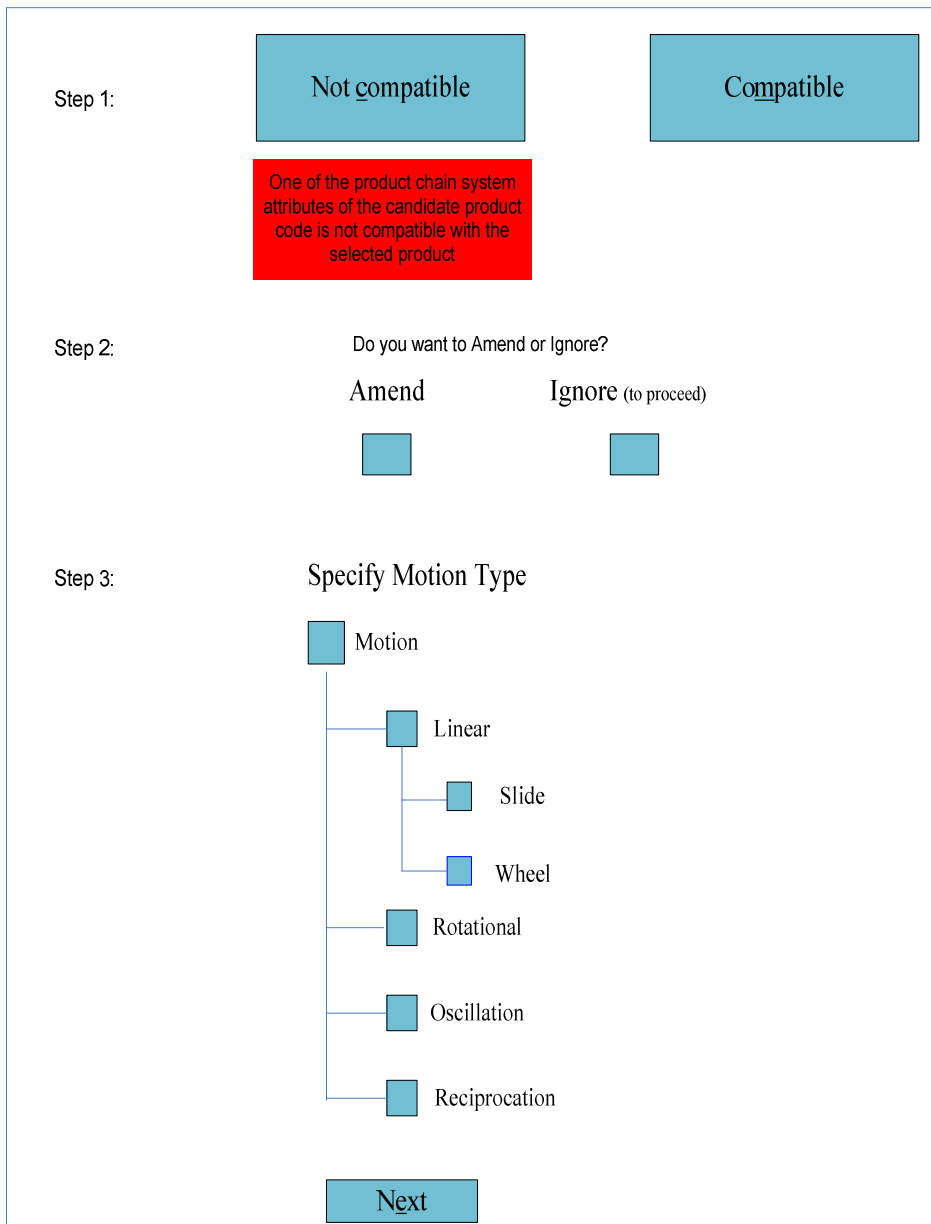
Figure 4.4: Model of Product Compatibility Check

SYSTEM EXECUTION OF USER'S COMMAND

Every command issued by the customer/user is executed by the system internally. The execution carried out in Stage 1 Task B is as follows:

Task 1: Compatibility Check

System: check if the internal motion property of the selected product and the candidate product are the same.

"If Yes", proceed to the next modification stage;

"If No", show error message: "*the internal motion compatibility of the candidate product code is not the same as with the selected product*".

Task 2: Amend or Ignore Command
System:

If Ignore, then proceed to the next modification stage

If Amend, show the applicable motion types (Linear: slide and wheel, Rotational, Reciprocating, and Oscillating)

Then, add drive module sub-assembly to the selected product assembly, and

If Linear, add wheels, rack and pinion to the drive module S/A, then constrain rotation, oscillation and reciprocation;

If Rotation, add rack, pinion and crank to the drive module S/A, then constrain linear, oscillation and reciprocation;

If Oscillation, add crank and linkage to the drive module S/A, then constrain linear, rotation, and reciprocation;

If Reciprocation, add crank and gear to the drive module S/A then constrain linear, rotation, and oscillation.

4.7.2. Stage 2: Displaying of the Parameters that Define the Product

There are parameters that define each of the products. Only one product can be analysed per time and that is the selected product. These parameters are used to analyse the selected product so that the customer/user will have the understanding of the product to be modified. On seeing the picture and composition of the product the user will know what he/she needs on the product in order to get his/her intended product. The parameters used in analysing the product are as follows -

(I). The Product Assembly and Model Structure: this shows the picture and the module assembly and sub-assemblies of the product. The module assembly involves the placement and fastening of a sub-assembly or more sub-assemblies into or upon another [87]. It is of importance to understand the nature and the structure of dependencies that exist between parts in a product module assembly to be able to carry out a proper modification on it. One of the designs for assembly guidelines [88] that were used here is the use of module sub-assemblies instead of parts which greatly simplifies the final product assembly.

While looking at the displayed product picture, the customer/user will have an idea of what part of the product will need to be modified and what module will need to be changed in order to conform to his/her required product. Each of the labelled sub-assemblies of the product when clicked on or the cursor is placed on it gives its component(s) part details. The essence of this is to make the system as simple as possible for the user/customer to understand.

(II). Hierarchical Module Sub-Assembly structure: the best way to represent the hierarchical relationship between the various modules of an assembly is by using an assembly tree [89]. The product itself represents an assembly while the modules that are combined together to form the assembly are the module sub-assemblies. The hierarchical module sub-assembly structure shows the parts that form the module sub-assemblies. The module sub-assemblies are considered as single parts when inserting them into the main assembly. Figure 4.4 shows a product module assembly structure with the assembly consisting of four sub-assemblies, and these sub-

assemblies are further broken down into sub-assemblies. The structure represents a product assembly sequence by which the product assembly can be produced.
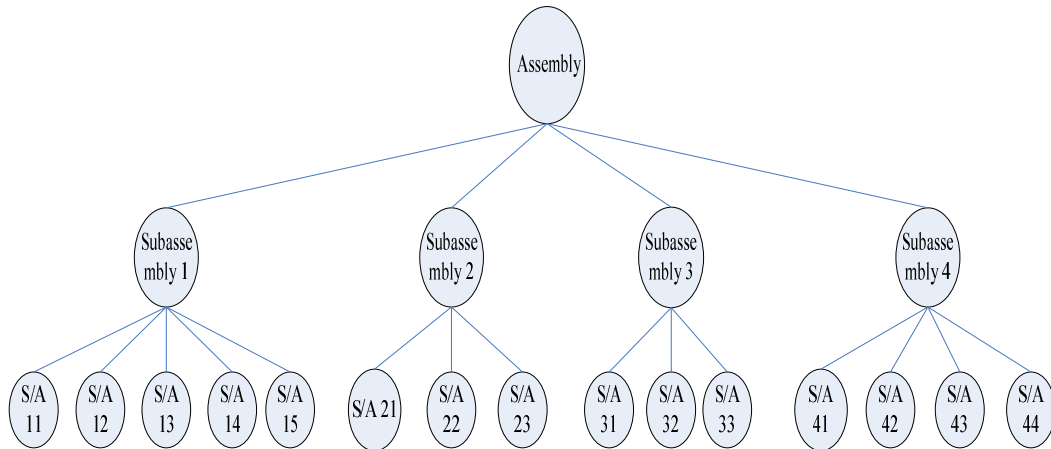
Figure 4.5: Product Modules Assembly Structure

(III). Mating Conditions, Attachment Type and Constraint in the Product:

Mating conditions define how the modules are attached to one other [36]. Mating features information can be provided interactively with ease because mating features are simple graphics entities such as faces and centrelines. The reason why mating condition is incorporated into the system is because it automatically computes and stores for each module sub-assembly the transformation matrices that merge [89] sub-assembly modules into their product assembly since the modification process will involve disassembly and then re- assembly of the product. It also helps to determine the appropriate position where the customer/user can place the module sub-assemblies in an assembly for the product to be assembled. The mating condition will be represented by its type and the two faces that mate. Table 4.26 shows the model of the product mating condition, attachment type and the constraint.

Table 4.26: Product Mating Condition, Attachment type and Constraint

Part Surface		Constraint	Attachment Type	Mating Condition
F_1	F_2	"Type"	Name	Kind
F_2	F_3	"Type"	Name	Kind
F_3	F_9	"Type"	Name	Kind
F_4	F_{19}	"Type"	Name	Kind
F_5	F_2	"Type"	Name	Kind
F_6	F_2	"Type"	Name	Kind
F_7	F_{19}	"Type"	Name	Kind
F_8	F_9	"Type"	Name	Kind
F_9	F_{12}	"Type"	Name	Kind
F_{11}	F_{12}	"Type"	Name	Kind
F_{12}	F_{14}	"Type"	Name	Kind
F_{13}	F_{15}	"Type"	Name	Kind
F_{14}	F_{13}	"Type"	Name	Kind
F_{15}	F_{16}	"Type"	Name	Kind
F_{16}	F_{17}	"Type"	Name	Kind
F_{18}	F_{19}	"Type"	Name	Kind
F_{19}	F_{23}	"Type"	Name	Kind
F_{20}	F_6	"Type"	Name	Kind

In order for the mating condition to work effectively in the modification process, the mating feature between a pair of module sub-assemblies has to satisfy the conditions of constraints such as "against", "fit", "tight fit", "contact", "co-planar", "semi-fit", "against-fit", "screw-fit", "fixed", "circular- centre", or "circular-fit". These constraint terms are defined as follows -

1. "Fit" condition holds between cylindrical faces - a shaft cylindrical face and a hole cylindrical face. The centreline of a shaft and a hole are collinear, their diameters are equal. Four points on the two parts coincide. That is, all three translational movements are constrained.

2. "Contact" condition is specified by requiring two points on the two mating modules to coincide (linear contact).

3. "Against" condition holds between two planar faces or between a planar face and a cylindrical face (shaft). Translational movement is constrained in one direction.

4. "Tight Fit" condition describes fits between parts where the force to rotate one module sub-assemble relative to another is too great to be called a rotational degree of freedom.

5. "Against" and "Fit" conditions do allow both rotational and translational freedom of movement between mating parts. But there are parts with the "against" or "fit" condition where rotational and translation, or both are not permitted. In this case, "contact" and "tight fit" are used.

6. "Co-planar" condition holds between two planar faces when they lie in the same plane. The "co-planar" condition is the complement (opposite) of the "against" condition, and is satisfied by forcing the two normal vectors of the faces n_1 and n_2 to be in the same direction.

7. "Semi-fit" condition holds when only two translational freedoms are constrained

8. "Against-fit" condition allows no rotational freedoms.

9. "Screw-fit" condition allows only screw restriction of translational and rotational freedom; it limits the axial motion.

10. "Fixed" condition permits two faces to attach to each other with no DOF.

11. "Circular-Centre" condition allows a short bar with circular X-section to fit into two opposite holes with the same X-section.

12. "Circular-Fit" condition allows a long bar with circular X-section fits into two opposite holes with the same X-section.

NOTE: A translational constraint indicates that the module sub-assembly cannot move in a given direction while a rotational constraint specifies limits of rotation of the module about a given vector.

Another aspect of a mating condition that is relevant to the product modification process is the Attachment type.

Attachment type is categorised into rigid, non-rigid, and conditional.

(i). Rigid Attachment: this occurs when no relative motion is possible between the modules and the attachment is permanent. Examples includes permanent fasteners

(rivets, snaps), tight (pressure) fit, glued, magnetic attachment, brazed, gravity friction etc.

(ii). Non-Rigid Attachment: occurs when the modules cannot be separated by an arbitrarily large distance but relative motion between the two sub-assemblies is possible. This type of attachment is non permanent e.g. clearance fit, slide, screw etc.

(iii). Conditional Attachment: this type is related to module sub-assemblies supported by gravity but not strictly attached.

(IV). Link Structure:

The Link structure is a complete set of information required to describe the type of attachment and mating conditions between the mating pair. Each constraint links one surface of a module sub-assembly/part to a surface of another one and the surface definitions [36] are taken from the module library. The Link structure shows which part is attached to other parts and through which surfaces. The type of link and the mating conditions can also be shown. The link structure can be derived from constraints, or need to be added to the model if the spatial position of parts is defined with transformation matrices.

When any changes are made on the product assembly during the modification process, the system will automatically effect/modify the changes in the link structure of the product. Figure 4.5 shows an assembly structure of a product based on the concept of link structure.
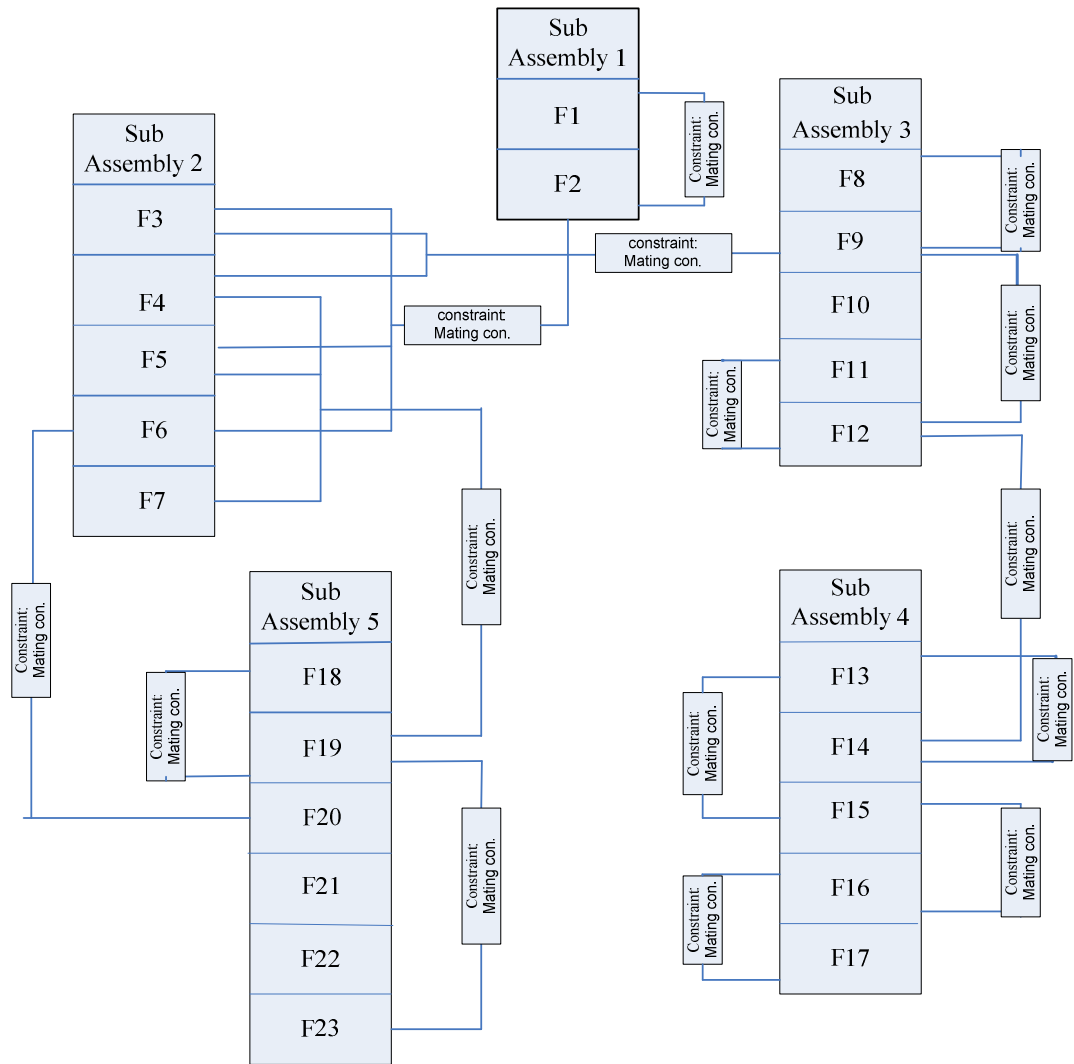
Figure 4.6: Link Structure Representation of a Product.

(V). Product Module Library:

This has been discussed in detail in Chapter 3. Of note with the product module library is that its sub-assemblies/parts are arranged in hierarchical order of the link assembly.

4.7.3. Stage 3: User Input Parameters for Modification

This is the main stage where the modification of the product actually occurs. Whatever changes that need to be carried out on the product module or part are done here. The system will prompt the user/customer through the task for what is to be done. The following procedure is carried out in changing the product module sub-assembly features.

Task: Start modification for changes required on the selected product.

The user is asked to begin to effect the changes he/she wanted on the selected product.

<u>NOTE</u>

For the modification initiated to be effected, the following criteria must be satisfied -

  i.   *The product part/module sub-assembly must be properly constrained*
  ii. *Modification can only take place where mating conditions are met (that is, where mating pairs or attachment occur)*

The user/customer changes or modifies the product sub-assembly/part by selecting and modifying its parameters. This is carried out as follows:

Modification Procedure:

Sub-task 1: select the part/module sub-assembly from the main module library

Sub-task 2: drag the part/module from the library where it is unconstrained; place the product ready to reach intermediate position where the constraint position will change

Sub-task 3: bring the part/module sub-assembly to the assembly position to complete the part mating process. As the changes to the product are effected, the product link structure is automatically updated since it is programmed to interlink with the product module library.

Figure 4.6 illustrates the process of modification that was explained above.

The result is displayed on the product user's interface. If the modification is accepted then the user saves the new product and if not, the user is prompted to repeat stage 3 again. If no feasible modification is achieved (that is, the user is not satisfied with the modified product), the system prompts him/her to exit and re-start the process again.
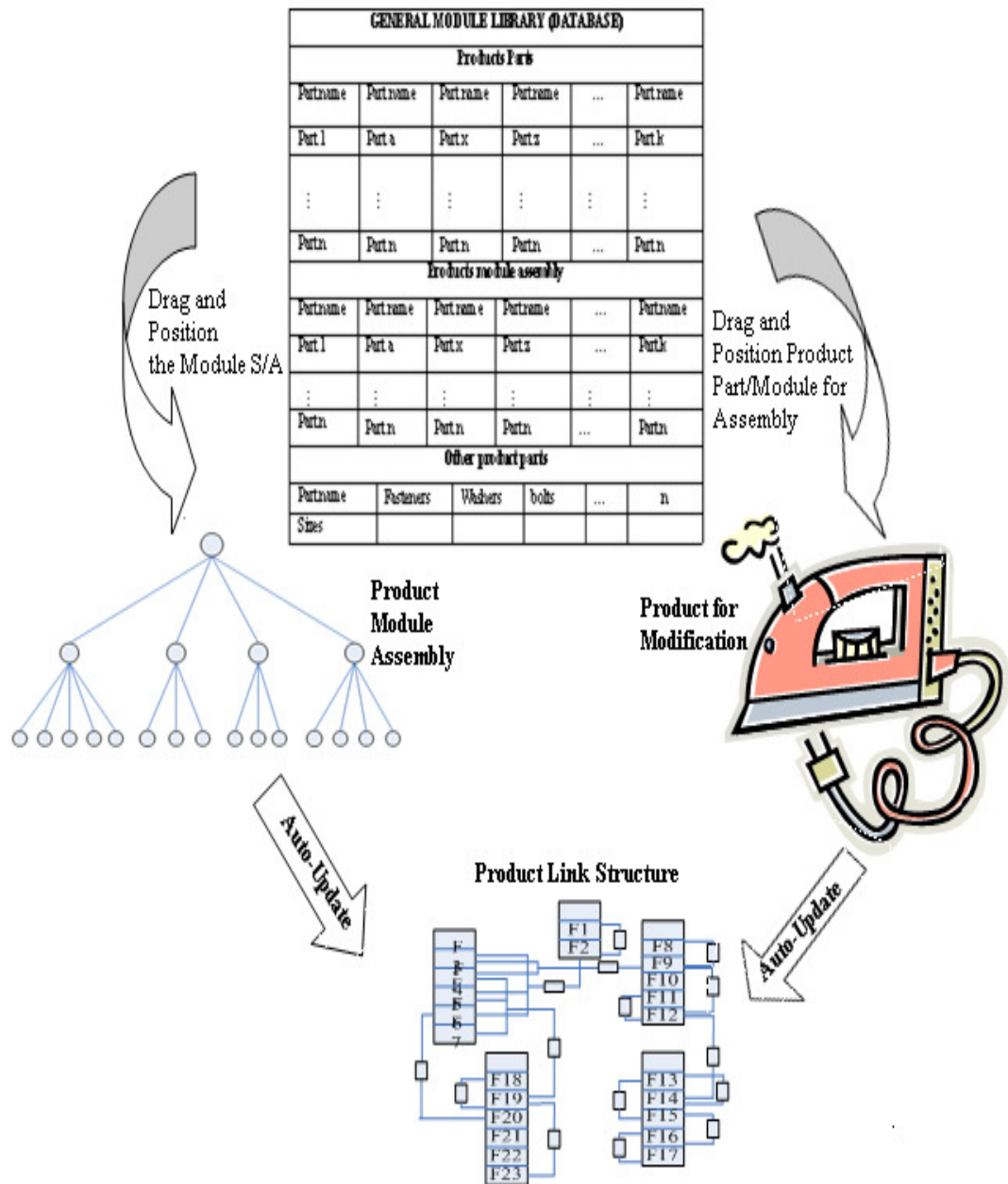
Figure 4.7: Process of Modification

4.8 Conclusions

This chapter discussed the framework and architectural representation for the design of a CLD system. It described the template for the PCS used by the customers/users to build up their desired product.

The chapter presented the methodology for the retrieval of product codes that are similar to the candidate code. Here, two methods were analysed with the weight factor method chosen to be the appropriate method for this work because of its ability to retrieve/match general product codes of similar products no matter of the location of the product in the attributes.

Another aspect of the discussion in this chapter was the customer product code generation. This showed how the user/customer can combine all the attributes together to generate a desired product code. A test was carried out using a suggested product code to validate the genuineness of the process which proved to be successful.

Finally, the chapter also explained the modification process for the retrieved product code and the modification stages. The modification process was divided into two sections for easy understanding. The first section is the user-friendly interactive section which permits the user to "manipulate" any part of the product for modification. The second section is where the execution of the customer input data takes place. The three stages of product modification that needed to be carried out before the selected product is transformed into the candidate product were also analysed in detail. One of the advantages of these stages is that they give flexibility to the customer/user during the modification process so that the customer/user could come up with the exact product he/she desires. It also integrates the customer as a co-designer.

CHAPTER FIVE

CLD SYSTEM TESTING AND EVALUATION

5.1 Introduction

Having described the conceptual architecture and framework for the design and development steps of the CLD System in the preceding chapter, the objective of this chapter is to evaluate the feasibility study of the design and development by testing the design using a case study example.

It is of utmost importance to verify that the methods of gathering information from the customer or user in regard to their product, generating of product code, retrieving of similar product codes if the candidate (customer/user) product code is not found in the database, and modifying/customising the retrieved product to conform to the customer/user configured or required product entered for the CLD system work properly.

This verification process took a lot of time to carry out and this is because getting the required information from the customer, the coding of product and retrieval of the same was manually inputted at first before using the supervised learning of ANN to simulate the product codes in the database in order to rank them based on their closeness to the candidate product and retrieved the similar product code. The verification process of the CLD system is presented to show the credibility and reliability of the work carried out.

The chapter also evaluates the CLD system modification of a simple product into a more complex product to determine the feasibility of the system under study.

5.2 CLD System Testing

The testing was carried out to ensure that the study undertaken can actually work in reality. The verification of the CLD system was accomplished by testing each method used in stages as follows:

1. Test was carried out to check if the attributes in the Product Chain System of the CLD will generate a product code for the customer/user based on the input data supplied.
2. Test was carried out to check if the similarity retrieval system used will be able to search and retrieve the closest product code to that of the candidate product code.
3. Test was also conducted to check if the Weight Factor used is capable to rank the retrieved product codes that were similar to the candidate product code according to their closeness to the candidate product based on the similarity index values.

The above stated tests that were carried out were documented in chapter four under each of the methods.

5.3 CLD System Evaluation

The evaluation of the CLD System is intended at measuring the feasibility of the theoretical work. Based on this, the CLD System practicability was examined by using the product example: Generating the customer product for a complex product and modification of the simpler product into a complex product.

5.3.1 Generation and Modification of User Intended Product

The product example involved using a customer data input into the system in which the product is assumed to be complex; in this case a bicycle, but the retrieved product (exercise bike) was simpler in nature when compared with the customer candidate product. And as a result, the simple product has to be modified in order to get the complex product which is the candidate product. In order to achieve this aim, the following steps were taken:

STEP 1: GETTING CUSTOMER/USER PRODUCT CODE

By using the Product Chain Structure template, the information about the product from the customer/user is gathered.

PF = {App, Ext M, Int M, Ene S, PoR, Max D, Wei, Sha P, Mat P}

System: What function will the product perform and where to use it?

App= {Apl, Spo, Tol, Tra},

Customer: product to be used for sporting or recreation

Spo= {In D, Out D},

System: is it for indoor or outdoor sporting or recreation?

Customer: for outdoor sporting

Out D = {Whl, Spo T, Oth}

System: what kind of outdoor product?

Customer: one with wheels

System: the wheels have two options, which of it do you prefer?

Whl Op= {with drive, without drive}

Customer: the one with drive

*System: **Wheels with drive [A]***

System: for your product selection to be complete, you need to reference your application with other attributes.

What kind of external motion (visible movement) will your wheels possess?

Ext M= {Fixed, Moving, Handheld},

Customer: should be able to move

System: what kind of movement

Customer: just to move

*System: **wheels that can move [E]***

System: what the type of internal motion for the product?

Int M= {Linear, Rotary/Rotation, Reciprocation, Oscillation},

Customer: to have linear motion

*System: **wheels that can move having linear inner motion [I]***

System: what kind of energy source will the product have?

Ene S= {Manual, Battery, Electric mains, Fuel},

Customer: is to be manually operated

*System: **wheels that can move having linear inner motion operating manually [S]***

---

*System: **no power is required for this product since it will operate manually.***

System: of what maximum dimension (size) will your product be?

Max D= {L (min.) of ≤100cm, L (max.) of >100cm},

Customer: the size should be greater than 100cm

System: the dimension you selected has two options

L (max.)= {>100≤150, >150}

Customer: less than 150cm is ok

*System: **wheels that can move having linear inner motion operating manually with size of less than 150cm [D]***

System: what will be the maximum weight of the product?

Wei= {Light, Medium, Heavy}

Customer: light in weight

System: the selected weight has two options

Lo= {medium, super}

Customer: medium light weight is preferred

System: **wheels that can move having linear inner motion operating manually with size and weight of less than 150cm and 50kg respectively [W]**

System: how do you want the product to look like in shape?

Sha P= {elongated, flat, box-like, rounded, irregular}

Customer: flat in shape

System: **wheels that can move having linear inner motion operating manually with size and weight of less than 150cm and 50kg respectively and flat in shape [F]**

System: what material will the product made of?

Mat P= {Metal, Ceramic, Elastomer, Plastic, Composite, Wood}

Customer: should be made of composite material

System: **wheels that can move having linear inner motion operating manually with size and weight of less than 150cm and 50kg respectively and flat in shape and made of composite material [M]**

The product data gathered from the customer input in step 1 is translated into the product code through the structure shown in figure 5.1. Therefore, the product code gathered is given below:

A222100 E22 I2 S1 P0 D21 W11 F2 M5
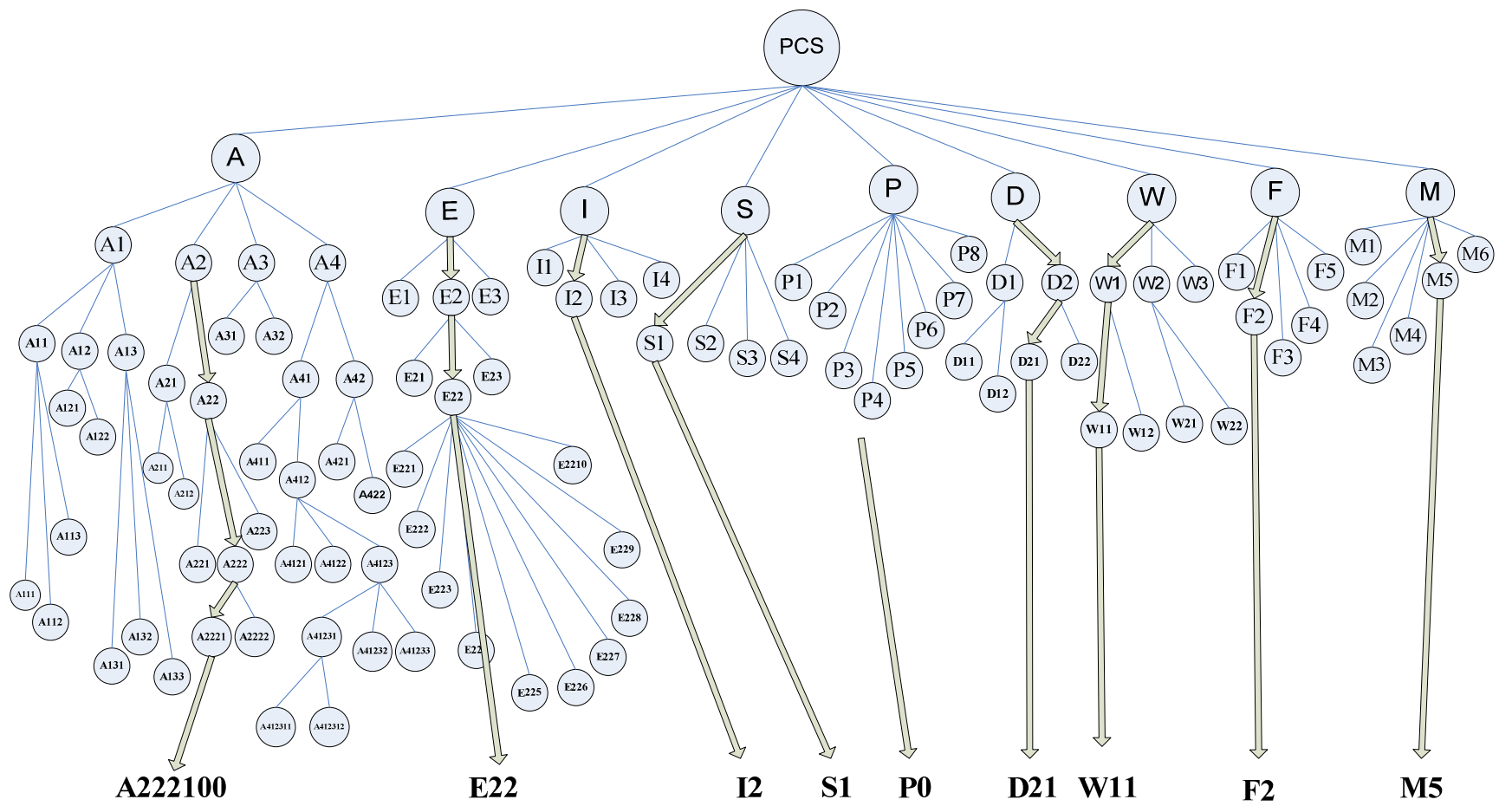
Figure 5.1: Coded Product Chain Structure for Generating Customer Product Code

STEP 2: SEARCHING THE DATABASE FOR PRODUCT CODE

From table 5.1, the product codes database shows no match for the customer product input data.

System: no match was found for your product in the database. The system will search for products similar to your intended product in the database.

STEP 3: RETRIEVAL OF SIMILAR PRODUCT CODES

In order to generate a similar product code, the system carried out the following sub-steps:

(1). The system allocates WF to the customer generated product code: the customer/user product code is assigned WF values which must total up to 100% as explained in the previous chapter and is shown in table 4.2;

A222100 (46) E22 (12) I2 (8) S1 (7) P0 (5) D21 (4) W11 (5) F2 (6) M5 (7)

(2). the system Generates WF values for all the product codes in the product database: The procedure involved assigning the WF values for all the products have been explained in chapter four. The WF values generated are shown in table 5.2

(3). the system Ranks the Product codes: The allocated WF values of the product codes are ranked automatically with the highest value on top which is shown in table 5.3. The higher the WF value, the more similar the product code is to the candidate code gathered from the customer.

Table 5.1: Model of Product Codes Database

Application	External Motion	Internal Motion	Energy Source	Power Rate	Maximum Dimension	Weight	Shape	Material	Product Database
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle
A211000	E10	I2	S1	P0	D21	W11	F5	M5	Exercise Bike
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter
A112000	E10	I3	S3	P3	D11	W11	F3	M4	Blender
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle
A111000	E10	I2	S3	P8	D12	W12	F3	M4	Dryer
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift

Table 5.2: Assigning of the Weight Factor for each Attributes

Application	External Motion	Internal Motion	Energy Source	Power Rate	Maximum Dimension	Weight	Shape	Material	Product Database
A223000(26)	E22(12)	I2(8)	S1(7)	P0(5)	D22(3)	W12(3)	F2(6)	M1(-)	Trolley(70)
A320000(-)	E30(-)	I1(-)	S1(7)	P0(5)	D11(-)	W11(5)	F2(6)	M1(-)	Scrapper(23)
A113000(-)	E30(-)	I1(-)	S3(-)	P6(-)	D11(-)	W11(5)	F3(-)	M5(7)	Pressing Iron(12)
A310000(-)	E30(-)	I2(8)	S3(-)	P5(-)	D12(-)	W11(5)	F3(-)	M1(-)	Blower Vac(13)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F2(6)	M1(-)	Hand Truck(47)
A421000(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F2(6)	M5(7)	Bicycle(54)
A211000(16)	E10 (-)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F5(-)	M5(7)	Exercise Bike(52)
A310000 (-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F5(-)	M1(-)	Wheel Barrow(41)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W21(-)	F2(6)	M1(-)	Pallet Truck(42)
A113000(-)	E21(8)	I4(-)	S3(-)	P1(-)	D11(-)	W11(5)	F3(-)	M4(-)	Table Fan(13)
A310000(-)	E22(12)	I2(8)	S3(-)	P5(-)	D12(-)	W11(5)	F5(-)	M1(-)	Lawn Mower(25)
A211000(16)	E10(-)	I1(-)	S3(-)	P2(-)	D22(3)	W12(3)	F5(-)	M5(7)	Tread Mill(29)
A222200(33)	E22(12)	I2(8)	S1(7)	P0(5)	D11(-)	W11(5)	F2(6)	M6(-)	Skate Board(76)
A222200(33)	E22(12)	I2(8)	S1(7)	P0(5)	D12(-)	W11(5)	F2(6)	M5(7)	Scooter(83)
A112000(-)	E10(-)	I3(-)	S3(-)	P3(-)	D11(-)	W11(5)	F3(-)	M4(-)	Blender(5)
A121000(-)	E30(-)	I3(-)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Stapler(17)
A112000(-)	E30(-)	I2(8)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Can Opener(25)
A320000(-)	E30(-)	I1(-)	S3(-)	P5(-)	D12(-)	W11(5)	F3(-)	M1(-)	Chain Saw(5)
A222200(33)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W11(5)	F2(6)	M5(7)	Unicycle(87)
A111000(-)	E10(-)	I2(8)	S3(-)	P8(-)	D12(-)	W12(3)	F3(-)	M4(-)	Dryer(11)
A121000(-)	E30(-)	I3(-)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Stapler(17)
A133000(-)	E30(-)	I3(-)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Stapler(17)
A133000(-)	E21(8)	I4(-)	S3(-)	P1(-)	D11(-)	W11(5)	F3(-)	M4(-)	Table Fan(13)
A113000(-)	E21(8)	I4(-)	S3(-)	P1(-)	D11(-)	W11(5)	F3(-)	M4(-)	Table Fan(13)
A113000(-)	E22(12)	I3(-)	S3(-)	P4(-)	D11(-)	W11(5)	F5(-)	M4(-)	Vacuum Cleaner(17)
A122000(-)	E30(-)	I2(8)	S1(7)	P0(5)	D11(-)	W11(5)	F3(-)	M1(-)	Can Opener(25)
A211000(16)	E10(-)	I3(-)	S1(7)	P0(5)	D12(-)	W11(5)	F5(-)	M5(7)	Stepper(40)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W21(-)	F2(6)	M1(-)	Pallet Stacker(42)
A412311(-)	E22(12)	I2(8)	S1(7)	P0(5)	D21(4)	W21(-)	F3(-)	M1(-)	Safe lift(36)

Table 5.3: Product Ranking Based on Similarity to Candidate Product Code

Application	External Motion	Internal Motion	Energy Source	Power Rate	Maximum Dimension	Weight	Shape	Material	Product Database	Similarity Index (%)
A222200	E22	I2	S1	P0	D21	W11	F2	M5	Unicycle	87
A222200	E22	I2	S1	P0	D12	W11	F2	M5	Scooter	83
A222200	E22	I2	S1	P0	D11	W11	F2	M6	Skate Board	76
A223000	E22	I2	S1	P0	D22	W12	F2	M1	Trolley	70
A421000	E22	I2	S1	P0	D21	W11	F2	M5	Bicycle	54
A412311	E22	I2	S1	P0	D21	W11	F2	M1	Hand Truck	47
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Stacker	42
A412311	E22	I2	S1	P0	D21	W21	F2	M1	Pallet Truck	42
A310000	E22	I2	S1	P0	D21	W11	F5	M1	Wheel Barrow	41
A211000	E10	I2	S3	P1	D21	W11	F5	M5	Exercise Bike	40
A211000	E10	I3	S1	P0	D12	W11	F5	M5	Stepper	40
A412311	E22	I2	S1	P0	D21	W21	F3	M1	Safe lift	36
A211000	E10	I1	S3	P2	D22	W12	F5	M5	Tread Mill	29
A112000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	25
A122000	E30	I2	S1	P0	D11	W11	F3	M1	Can Opener	25
A310000	E22	I2	S3	P5	D12	W11	F5	M1	Lawn Mower	25
A320000	E30	I1	S1	P0	D11	W11	F2	M1	Scrapper	23
A113000	E22	I3	S3	P4	D11	W11	F5	M4	Vacuum Cleaner	17
A113000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A121000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A133000	E30	I3	S1	P0	D11	W11	F3	M1	Stapler	17
A310000	E30	I2	S3	P5	D12	W11	F3	M1	Blower Vac	13
A113000	E30	I1	S3	P6	D11	W11	F3	M5	Pressing Iron	12
A111000	E10	I2	S3	P8	D12	W12	F3	M1	Dryer	11
A320000	E30	I1	S3	P5	D12	W11	F3	M1	Chain Saw	5
A113000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	5
A121000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	5
A133000	E21	I4	S3	P1	D11	W11	F3	M4	Table Fan	5
A112000	E1	I3	S3	P3	D11	W11	F3	M4	Blender	5

In order to generate a better Similarity Index Value (SIV) to that of weighing factor used for the retrieval system in Step 3 for the retrieval system, the SIV was generated automatically by using the Artificial Neural Network (ANN) [90] Program that was designed for this work.

The programming parameter text file is shown below:

```
/* --------------------- PARAMETERS.TXT ------------------------ */
/* Data file for the Customer-lead design project's NN system.  */
/* ----------------------------------------------------------- */
/* -------------------- Common Processing Parameters --------- */
INPUTS          34
EXAMPLES    609
/* ----------------- Input/Output Intervals -------------------- */
INPUT_0     0   4
INPUT_1     0   3
INPUT_2     0   3
INPUT_3     0   3
INPUT_4     0   3
INPUT_5     0   2
INPUT_6     1   3
INPUT_7     0   3
INPUT_8     1   4
INPUT_9     1   4
INPUT_10    0   8
INPUT_11    1   2
INPUT_12    1   2
INPUT_13    1   3
INPUT_14    0   2
INPUT_15    1   5
INPUT_16    1   6
INPUT_17    0   4
INPUT_18    0   3
INPUT_19    0   3
INPUT_20    0   3
INPUT_21    0   3
INPUT_22    0   2
INPUT_23    1   3
INPUT_24    1   3
INPUT_25    1   4
INPUT_26    1   4
INPUT_27    0   8
INPUT_28    1   2
INPUT_29    1   2
INPUT_30    1   3
INPUT_31    0   2
INPUT_32    1   5
INPUT_33    1   6
OUTPUT      0   100
```

```
/* --------------------- Neural Network Parameters ------------ */
HIDDEN_NODES          34
MAX_TOTAL_ERROR       0.001
LEARNING_RATE         0.2
MOMENTUM_TERM         0.2
RANDOM_RATE           0.1
ITER_RESULT_NN        1
ITER_STOP_NN          100000
/* -------------------- Training Examples --------------------- */
2 2 2 2 0 0  2 2  2  1  0  2 1  1 1  2  5 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 87
2 2 2 2 0 0  2 2  2  1  0  1 2  1 1  2  5 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 83
2 2 2 2 0 0  2 2  2  1  0  1 1  1 1  2  6 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 76
2 2 3 0 0 0  2 2  2  1  0  2 2  1 2  2  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 70
4 2 1 0 0 0  2 2  2  1  0  2 1  1 1  2  5 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 54
4 1 2 3 1 1  2 2  2  1  0  2 1  1 1  2  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 47
4 1 2 3 1 1  2 2  2  1  0  2 1  2 1  2  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 42
4 1 2 3 1 1  2 2  2  1  0  2 1  2 1  2  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 42
3 1 0 0 0 0  2 2  2  1  0  2 1  1 1  5  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 41
2 1 1 0 0 0  1 0  2  3  1  2 1  1 1  5  5 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 40
2 1 1 0 0 0  1 0  3  1  0  1 2  1 1  5  5 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 40
4 1 2 3 1 1  2 2  2  1  0  2 1  2 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 36
2 1 1 0 0 0  1 0  1  3  2  2 2  1 2  5  5 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 29
1 1 2 0 0 0  3 0  2  1  0  1 1  1 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 25
1 2 2 0 0 0  3 0  2  1  0  1 1  1 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 25
3 1 0 2 0 0  2 2  2  3  5  1 2  1 1  5  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 25
3 2 0 0 0 0  3 0  1  1  0  1 1  1 1  2  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 23
1 1 3 0 0 0  2 2  3  3  4  1 1  1 1  5  4 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 17
1 1 3 0 0 0  3 0  3  1  0  1 1  1 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 17
1 2 1 0 0 0  3 0  3  1  0  1 1  1 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 17
1 3 3 0 0 0  3 0  3  1  0  1 1  1 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 17
3 1 0 0 0 0  3 0  2  3  5  1 2  1 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 13
1 1 3 0 0 0  3 0  1  3  6  1 1  1 1  3  5 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 12
1 1 1 0 0 0  1 0  2  3  8  1 2  1 2  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 11
1 1 3 0 0 0  2 1  4  3  1  1 1  1 1  3  4 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 05
1 2 1 0 0 0  2 1  4  3  1  1 1  1 1  3  4 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 05
3 2 0 0 0 0  3 0  1  3  5  1 2  1 1  3  1 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 05
1 3 3 0 0 0  2 1  4  3  1  1 1  1 1  3  4 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 05
1 1 2 0 0 0  1 0  3  3  3  1 1  1 1  3  4 2 2 2 1 0 0 2 2 2 1 0 2 1 1 1 2 5 05
```

The common processing parameters are explained as follows:

Input and Output Intervals: the input and output intervals used are normalised input/outputs. The essence of this is to ensure that the values of the input and output were within the range 0 and 1.

- INPUT: this defines all the input attribute values [91] for the retrieval model, and their probabilities and it provide inputs to one or more hidden neurons.

Thirty-four (34) input attributes and 609 examples were used for the analysis of the products codes. These inputs are represented in tables 4.6 to 4.25.

- OUTPUT: this represents predictable attribute values for the retrieval model that is, the similarity between the products. The output margin used is between 0 and 100.

Neural Network Parameters

- *HIDDEN_NODES*: this receives inputs from the input neurons and provides the outputs to the output neuron. It has 34 nodes.

- *MAXIMUM_TOTAL ERROR*: this is the maximum amount of error that the iteration is permitted to carry out and on reaching this point/value it stops. The maximum total error used here is 0.001.

- *RANDOM_RATE*: this is used to initialise the connection weights with random small numbers.

- *ITERATION_RESULT_NN*: this shows the number of iteration at which the results are display. In this case, at every iteration the results are shown. If a higher number is used the learning process is speeded up, but the amount of information the user receives gets lower.

- *ITERATION_STOP_NN*: this is used to stop the system even if it can not converge to the pre-defined maximum total error. We used 10000000 values for the iteration to stop the process.

The Training Examples

These are the set of products attribute codes used in training the Neural Network. 609 examples were used in all which were generated from tables 4.6 to 4.25. Some of the training examples are listed in the appendices.

Figure 5.2 shows the similarity retrieval model of the neural network.
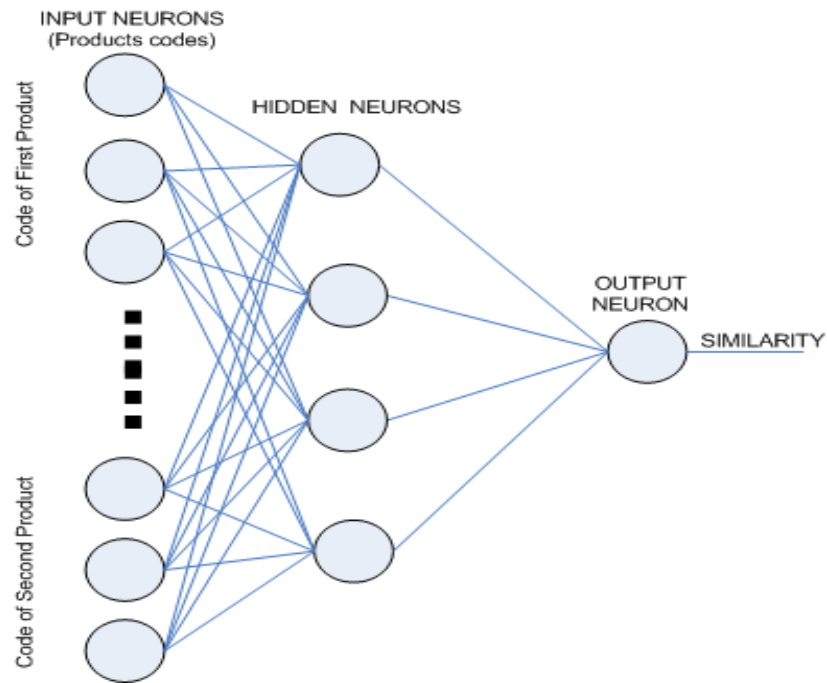
Figure 5.2: Similarity Retrieval Model of Neural Network.

The algorithm first evaluates and extracts training examples from the products database. Fifteen percent (15%) of the training examples, called the *holdout data* [92], is reserved for use in assessing the accuracy of the network. The system was evaluated throughout the training process through the training data after each iteration. When the accuracy no longer increased, the training process was stopped.

Since the product attribute codes used for the input are many, the algorithm provider (system) constructs a network for each of the product attribute as can be seen in figure 5.2.

The algorithm then used the value of the *HIDDEN NODES* parameter which was thirty-four (34) to determine the initial number of neurons to create the hidden neurons.

In order to program the Neural Network (NN), there are four steps involved. The steps are as follows:

STEP ONE

This represents the first step in programming the network. Digit 2 on the keyboard is entered into the system which instructs the system to start training the NN from parameters text *(PARAMETERS.TXT)*. The system then trained the NN based on the data contained in the parameter text file. Figure 5.3 shows the instruction screen of the system.
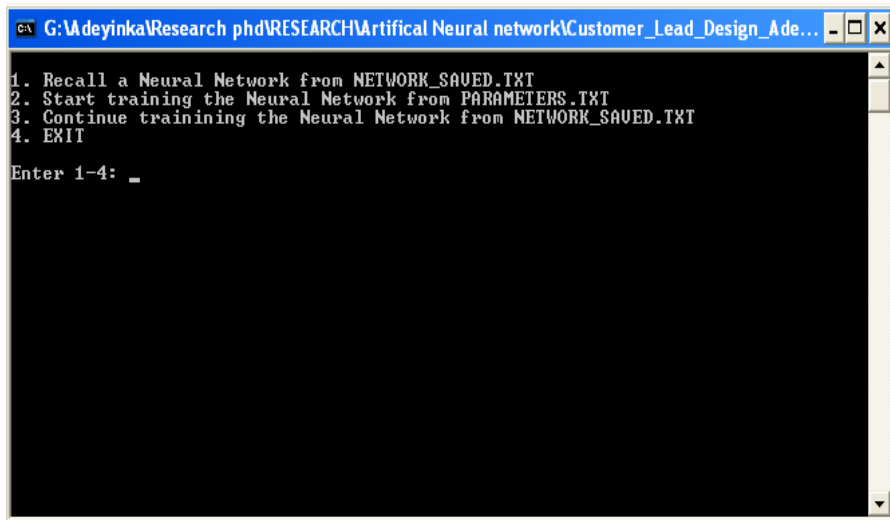
Figure 5.3: Instructing the System to Start Training the NN.

During the training process, the system assigns weights to the node connections between each layer of the NN. The algorithm calculates the degree of error, if any, and adjusts the weights that are associated with the inputs for that neuron, working backward from output neurons to input neurons in a process known as backpropagation [93]. The algorithm then repeats the process over the entire set of training data.

STEP TWO

After training the system, the results of the iteration are displayed as shown in figure 5.4 at the end of each of the iteration as stated in the parameters text file. After the programme reads the parameter file, all parameters are displayed on the screen. The user is then asked if they want to continue with the training process. When the training is completed, the result is automatically saved in the network saved text file *(NETWORK_SAVED.TXT)*.

Figure 5.4: Instructing the System to Continue Training the NN.

STEP THREE

In this step, after the training of the NN is completed which is based on the *MAXIMUM_TOTAL_ERROR* value and the *ITERATION_STOP_NN* value of the NN parameters, whichever of the two parameters value first reached will stop the training of the network. As can be seen in figure 5.5 the *ITERATION_STOP_NN* value of 0.001 was reached first which then ended the training after 24 hours training. The next stage here is to Recall the NN from the *NETWORK_SAVED.TXT* file. From the option displayed on the screen below, 1 is entered to recall the Neural Network from *NETWORK_SAVED.TXT*

Figure 5.5: Recalling the NN from Network Saved File after Training.

Once the NN is trained it can be recalled to evaluate unknown cases. For this, data that were not used for training the NN is used. The algorithm iteratively evaluates the unused examples. After the algorithm has evaluated the entire set of training data, the algorithm reviews the predicted and actual value at the output neuron. The result of the process is shown in figure 5.6a and 5.6b after the recall command has been activated.

Figure 5.6a: Result of the Recall Example Showing Examples and the Input.

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Figure 5.6b: Result of the Recall Example showing the Differences between Desired Output and Calculated Output.

STEP FOUR

This is the last and final step of the NN program. Digit 4 is entered to exit the programme which is done after the completion of the programme and result analysed.

RESULT ANALYSIS

Figure 5.5, shows the number of iterations run for the analysis which is 476503 and for 24 hours with maximum total error of 0.00100. From the result shown in figure 5.6a and 5.6b, one can see that the error margin between the desired output and calculated output are not much and can be neglected and this proved the validity of the process. For instance, when the first product attributes code (EX[0]) shown in figure 5.6a was compared with the intended product attribute code, the SI value which represents the desired output was 33% and the NN programme value which represents the calculated output was 33.0006451% as shown in figure 5.6b, their

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difference was -0.006451 and also, in example 26 (EX[26]) the desired output was 45.00000 while the calculated output was 44.920433 with difference of 0.079567. From these result, it shows that the retrieval system used for calculating the similarities among the products worked well.

Another aspect is that the setting of the maximum total error has great influence on the result. If a smaller maximum total error is used, it will refine the error margin close to zero and this will authenticate the result more but will take longer period/hours to run.

STEP 4: MODIFICATION OF THE SELECTED SIMILAR PRODUCT

STAGE 1: Product for modification is selected.

Task A: Check the result produced by the retrieval system and the Artificial Neural Network to choose the product that is very similar to the desire one based on Similarity index value (SI).
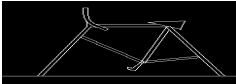
	Product Code Name	SI Value (%)	Pictorial View
☐	UNICYCLE	87	Click here to see Picture
☐	SCOOTER	83	Click here to see Picture
☐	SKATE BOARD	76	Click here to see Picture
☐	TROLLEY	70	Click here to see Picture
☐	HAND TRUCK	47	Click here to see Picture
☐	PALLET STACKER	42	Click here to see Picture
☐	PALLET TRUCK	42	Click here to see Picture
☐	WHEEL BARROW	41	Click here to see Picture
■	EXERCISE BIKE	40	
☐	STEPPER	40	Click here to see Picture
☐	SAFE LIFT	36	Click here to see Picture
☐	TREAD MILL	29	Click here to see Picture
☐	CAN OPENER	25	Click here to see Picture
☐	BLENDER	5	Click here to see Picture

Figure 5.7: Selection of Product for Modification.
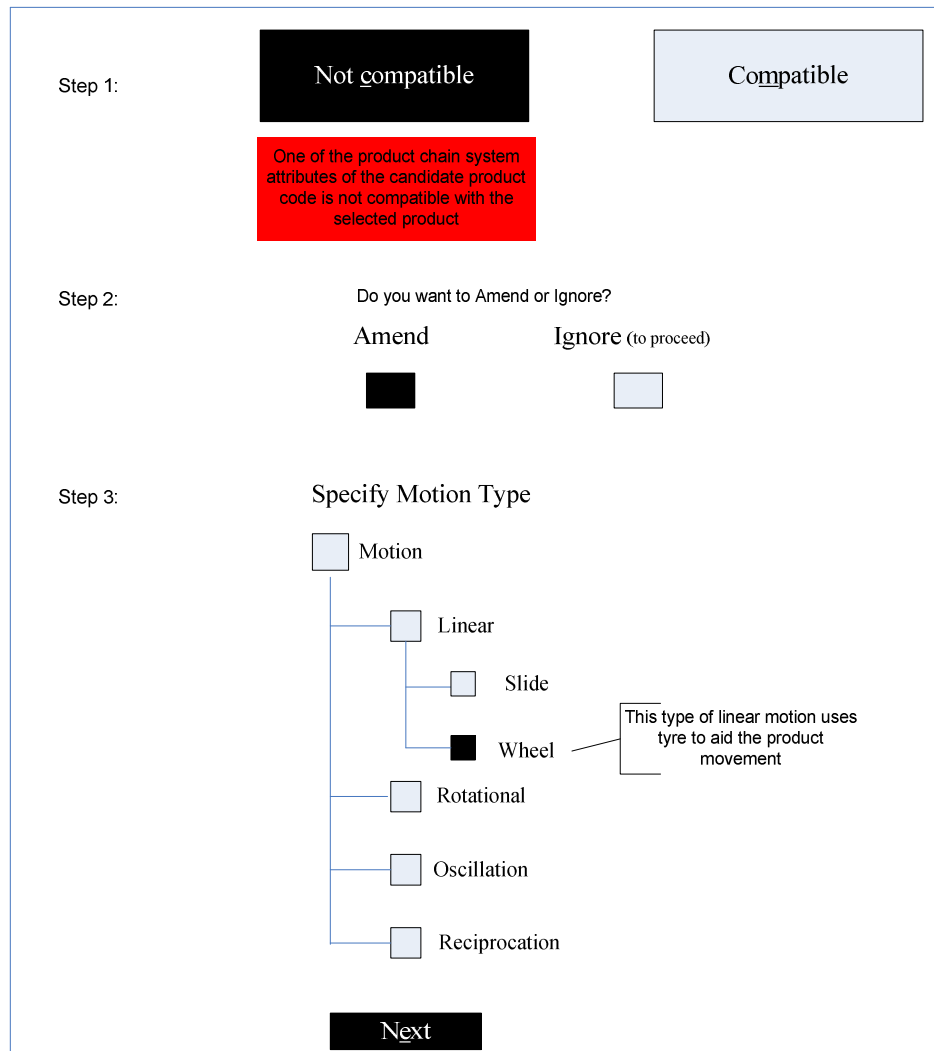
Task B: Product Compatibility Check.

Figure 5.8: Model of Product Compatibility Check.

STAGE 2: Parameters that define the product are shown.

Task: Selected product for modification/customisation is loaded into the system. This shows the in- depth details of the product such as follows:

I. ***The Product Diagram (the product's picture and its parts composition).***

The customer views the picture of the exercise bike as shown in figure 5.9 to see what modification is needed. When the cursor is placed on the drive system S/A, it shows the component of the sub-assembly.
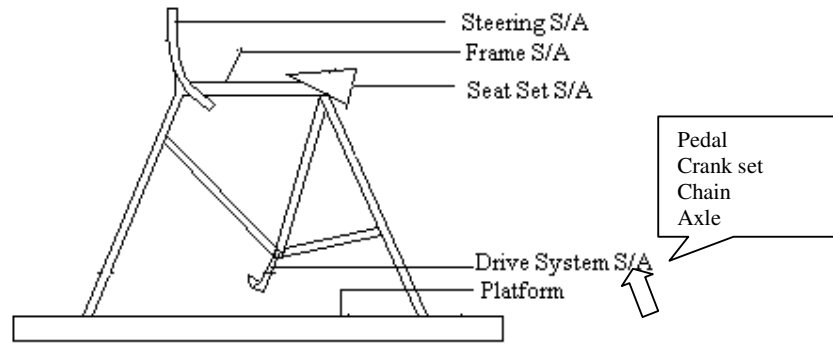
Figure 5.9: Schematic Picture of an Exercise Bike Showing the Product Sub-assemblies.

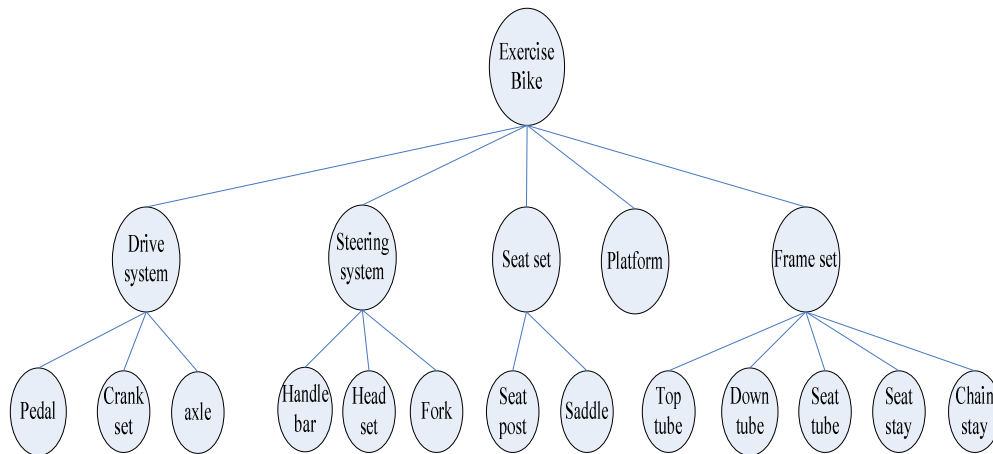*II.* ***Hierarchical Parts Assembly and Subassembly Structure***

Figure 5.10: Exercise Bike Module Assembly.

The customer views the product module assemblies shown in figure 5.10 to see the connectivity of the sub-assemblies.

III.   *Mating condition, Attachment type and Constraint in the Exercise bike*

Part Surface		Constraint	Attachment Type	Mating Condition
Saddle	Seat post	"fits"	Non –Rigid	Screw
Seat post	Frame	"fixed"	Rigid	Welded
Head tube	Frame	"fixed"	Rigid	Welded
Stem	Handle bar	"fixed"	Rigid	Welded
Stem	Head tube	"circular fits"	Rigid	Pressure
Crank arm	Gear	"fits"	Non –Rigid	Interference
Gear	Frame	"fits"	Non –Rigid	Clearance
Pedal	Crank arm	"tight fits"	Non –Rigid	Interference
Platform	Frame	"fixed"	Rigid	Welded

The mating conditions, attachment type and constraints of the exercise bike as contained in the system are shown above. The above table illustrates how the modules are connected together through what mating conditions, which attachment and the constraint that exist between the surfaces.

IV.   *Exercise Bike Link Structure*

This shows how the face of a module/part is attached to another module/part through its surface.
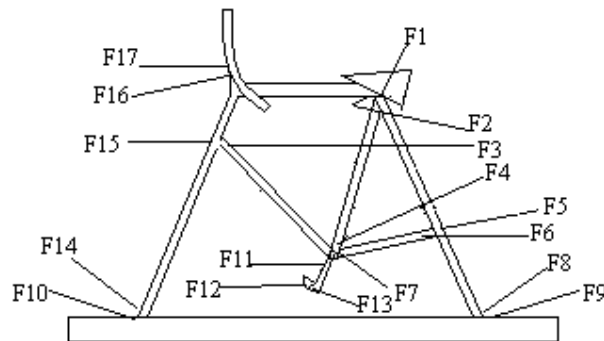

Figure 5.11: Schematic diagram of an Exercise Bike Showing the Module Faces.

The interconnecting link linking one module/part face to another and with the constraint and attachment type is illustrated in figure 5.12.
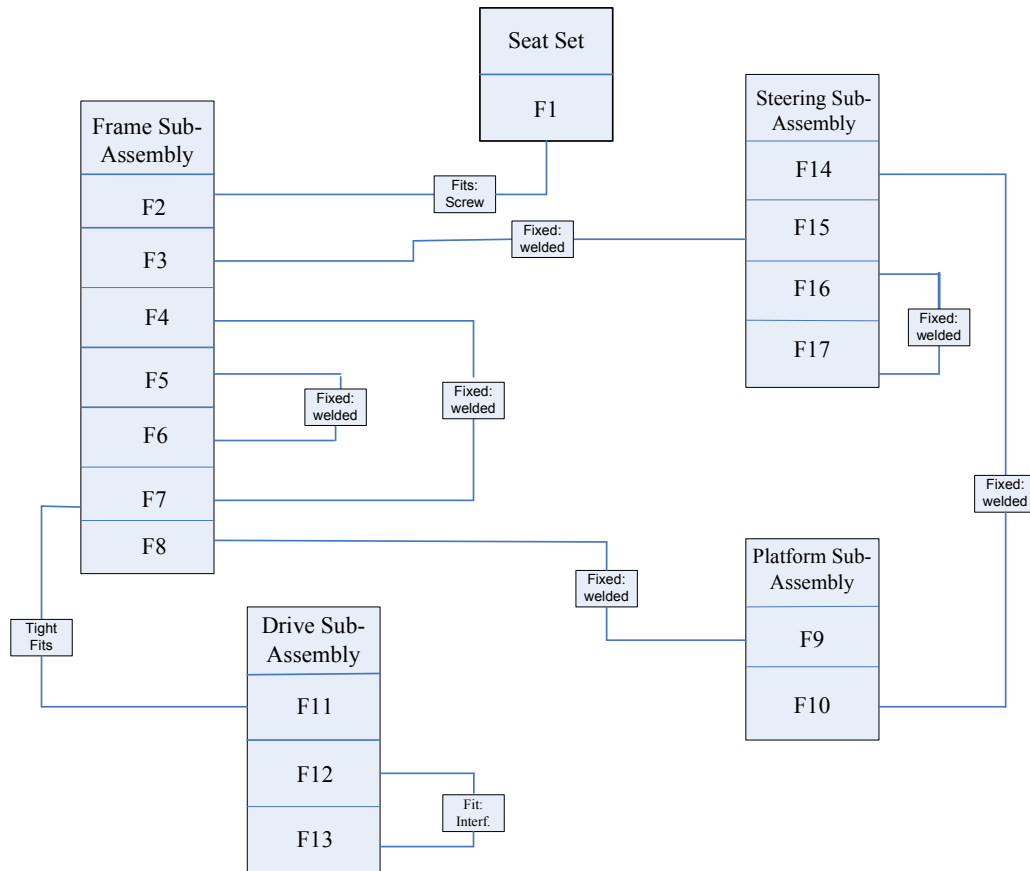

Figure 5.12: Exercise Bike link Structure with Constraint and Mating Condition.

Product Module Library:

The product part(s) are arranged in hierarchical order of the link assembly.

Part Name	Sub Assembly	Link Sequence
Top tube	Frame	Seat post
Down tube	Frame	Seat post
Seat tube	Frame	Seat post
Seat stay	Frame	Seat post
Chain stay	Frame	Seat post
Seat post	Seat set	Saddle
Saddle	Seat set	-
Handle bar	Steering	-
Head tube	Steering	Handle bar
Fork	Steering	Head tube
Crank arm	Drive	Gear
Pedal	Drive system	Crank arm
Platform	Frame / Steering	Seat stay/ Fork

STAGE 3**:** User input parameters for Modification.

Task: Start modification for changes required on the selected product.

Task 1: state action(s) to be taken for the following module parameters

(a). User interface in figure 5.13 shows the command to remove the platform

PRODUCT Module Description   Action Required

Module
Assembly

Seat S/A

Frame S/A

Drive S/A

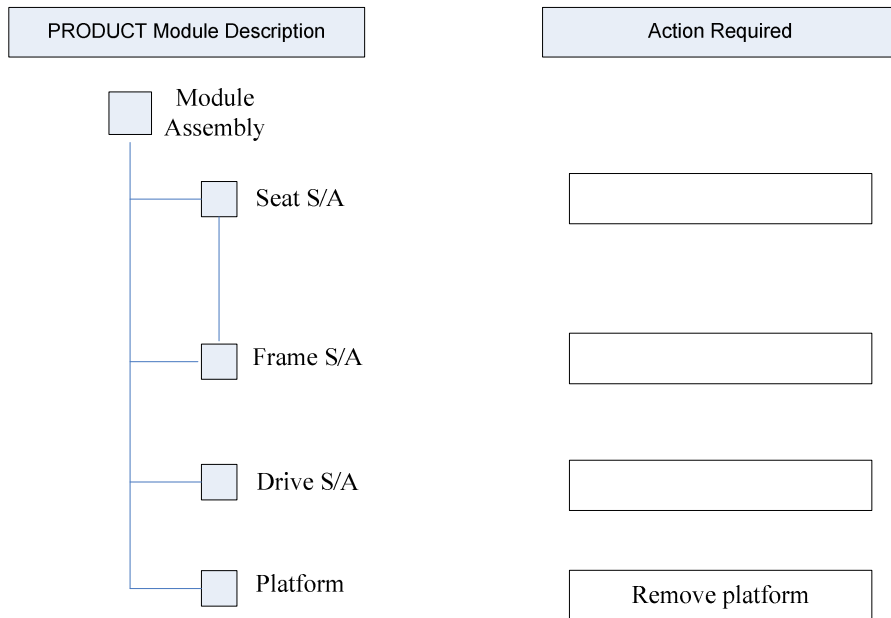Platform   Remove platform

Figure 5.13: User Interface to specify the removal Platform.

(b). Action Taken

1. Remove the platform from the steering module and the frame module

SYSTEM EXECUTION OF USER'S COMMAND

System: to remove the platform from the steering module and frame module

i.   Remove the mating condition between the platform and steering module
ii. Remove the mating condition between the platform and frame module

The platform was automatically removed by the system as can be seen on the user interface in figure 5.14.
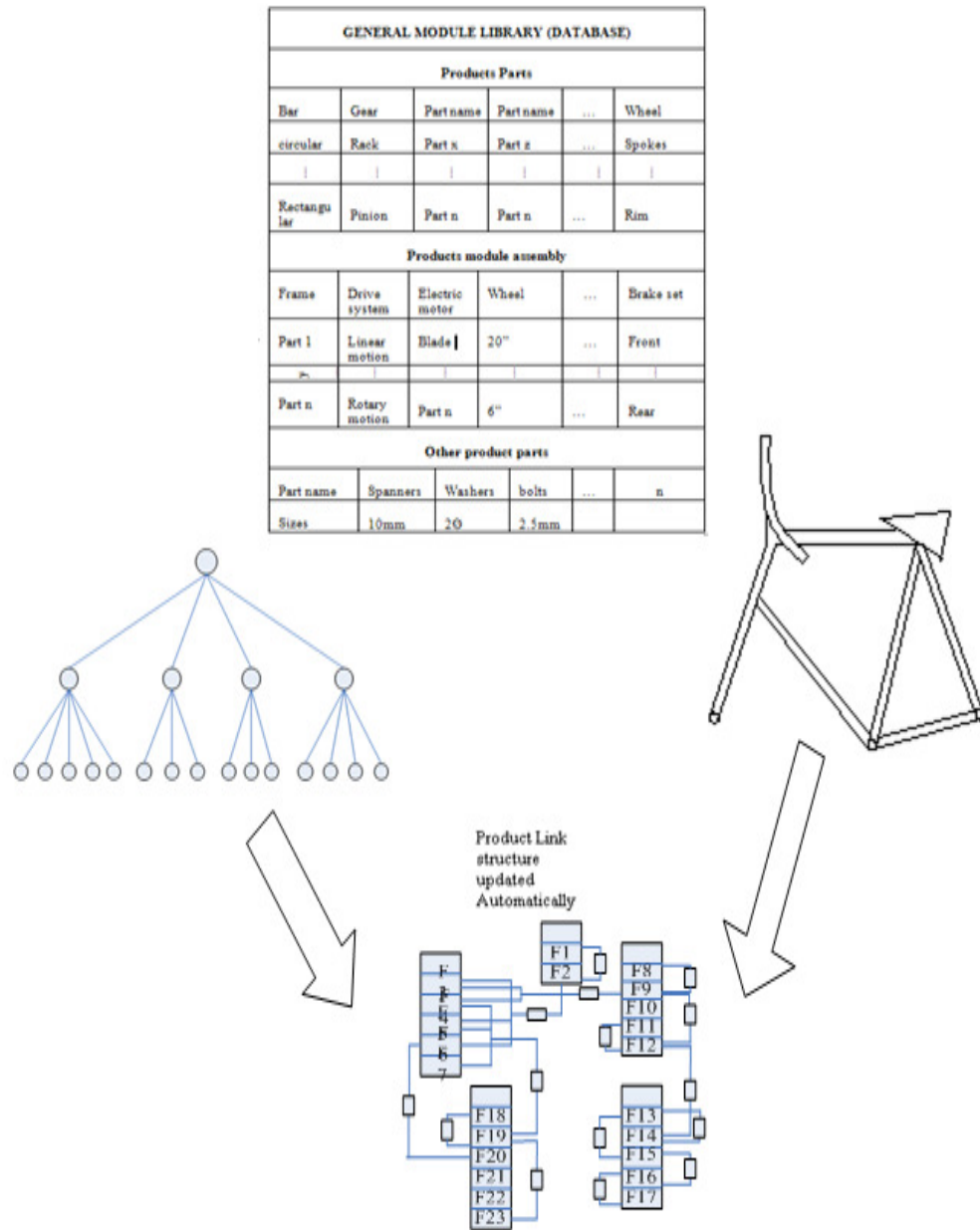
GENERAL MODULE LIBRARY (DATABASE)					
Products Parts					
Bar	Gear	Part name	Part name	...	Wheel
circular	Rack	Part x	Part z	...	Spokes
⋮	⋮	⋮	⋮	⋮	⋮
Rectangular	Pinion	Part n	Part n	...	Rim
Products module assembly					
Frame	Drive system	Electric motor	Wheel	...	Brake set
Part 1	Linear motion	Blade	20"	...	Front
⋮					
Part n	Rotary motion	Part n	6"	...	Rear
Other product parts					
Part name	Spanners	Washers	bolts	...	n
Sizes	10mm	20	2.5mm		

Product Link structure updated Automatically

Figure 5.14: User Interface Showing the Product without Platform.

Task 2: state action(s) to be taken for the following module parameters

(a). User interface in figure 5.15 shows the command to add wheels to the frame module and steering module

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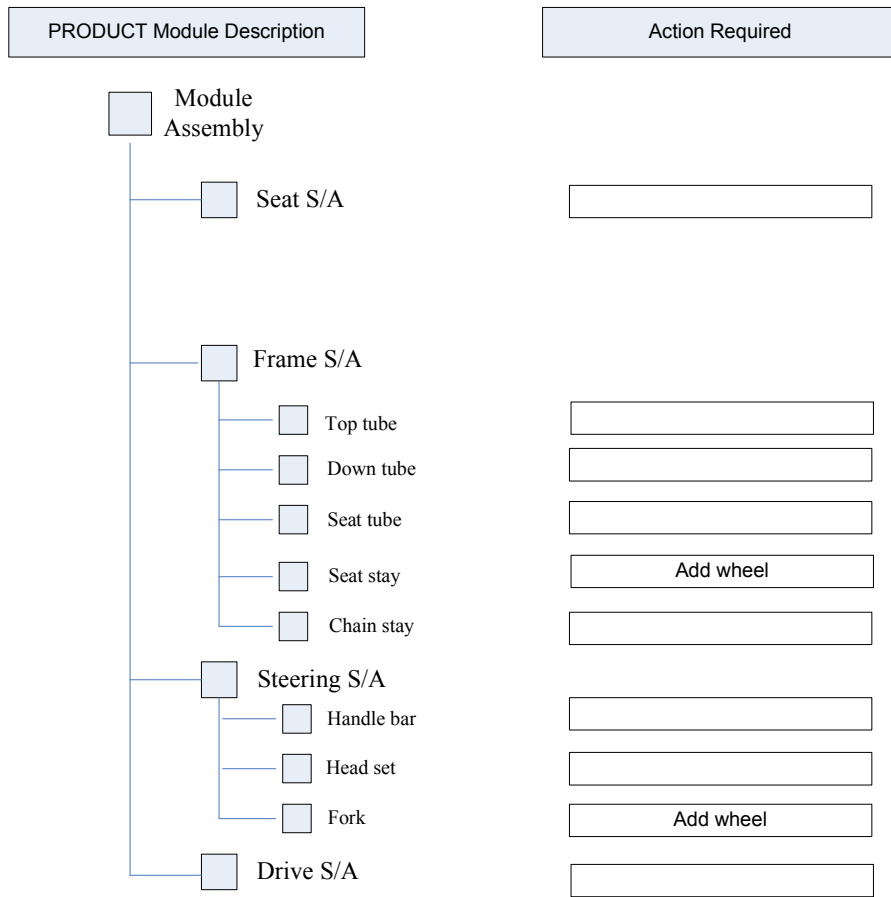| PRODUCT Module Description	Action Required
Module Assembly	
Seat S/A	
Frame S/A	
Top tube	
Down tube	
Seat tube	
Seat stay	Add wheel
Chain stay	
Steering S/A	
Handle bar	
Head set	
Fork	Add wheel
Drive S/A	

Figure 5.15: User Interface to specify the Wheels Addition to Frame and Steering Modules.

(b). Action Taken

1. Drag the selected wheels from the main modules library to the product point

2. Bring the selected wheels to the assembly position to complete the replacement task

SYSTEM EXECUTION OF USER'S COMMAND

System: to add wheels to the frame module and steering module

i.   Check the module S/A mating and attachment type for the module surfaces between the frame and the wheel. *"Mating possible, then proceed to next phase"*.

ii. Check the module S/A mating and attachment type for the module surfaces between the steering set and the wheel. *"Mating possible, then proceed to next phase"*.

iii. Attach module together and create constraint and mating condition between the frame module and the wheel module. *"Module attached and constraint created"*.

Figure 5.16 shows the user interface for the assembly of wheels to both the frame module and the steering module.
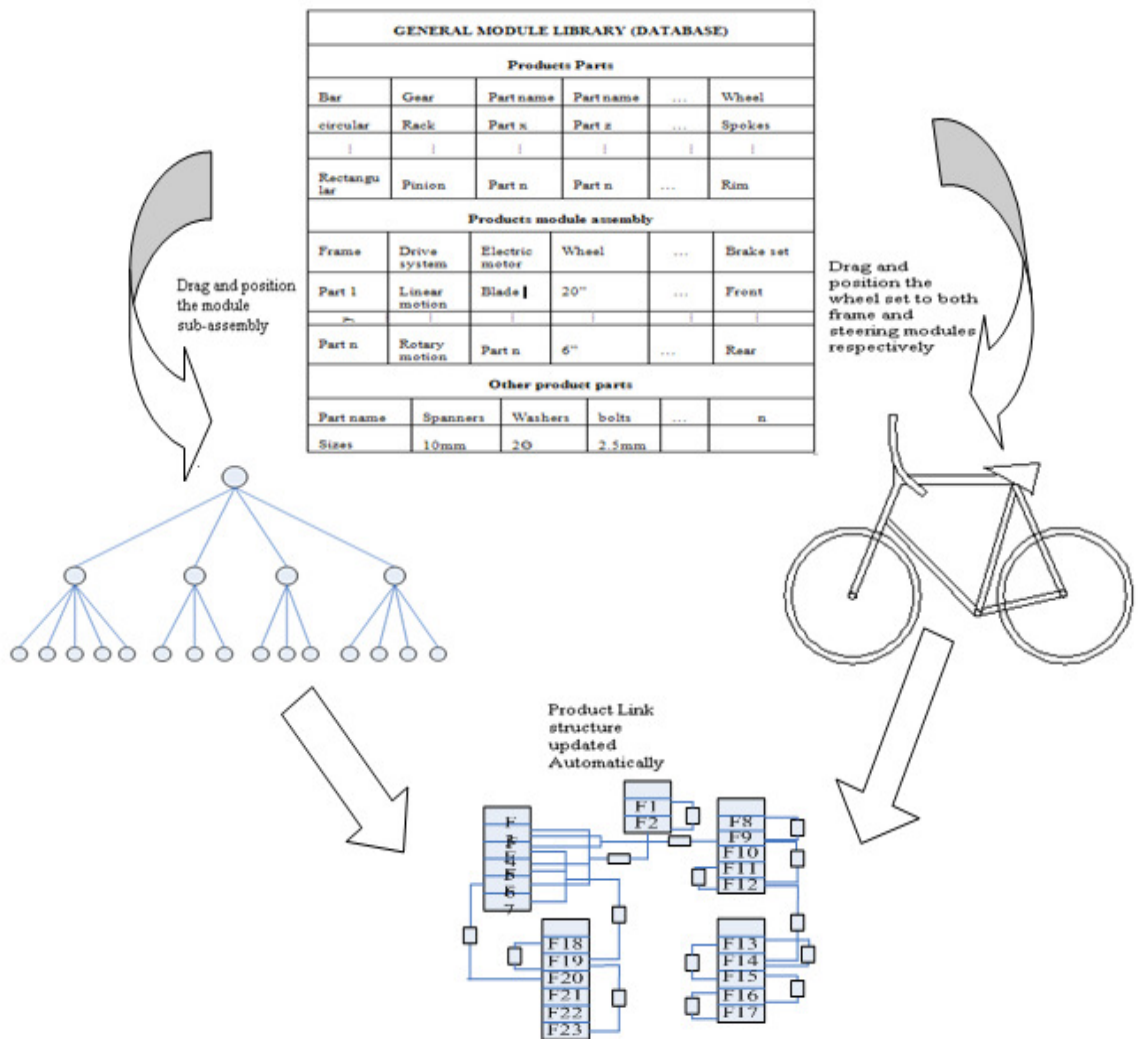

Figure 5.16: User Interface Showing the Wheel Module Assembly.

Task 3: state action(s) to be taken for the following module parameters

(a). User interface in figure 5.17 shows the command to add a complete drive set to the drive S/A to turn the wheel
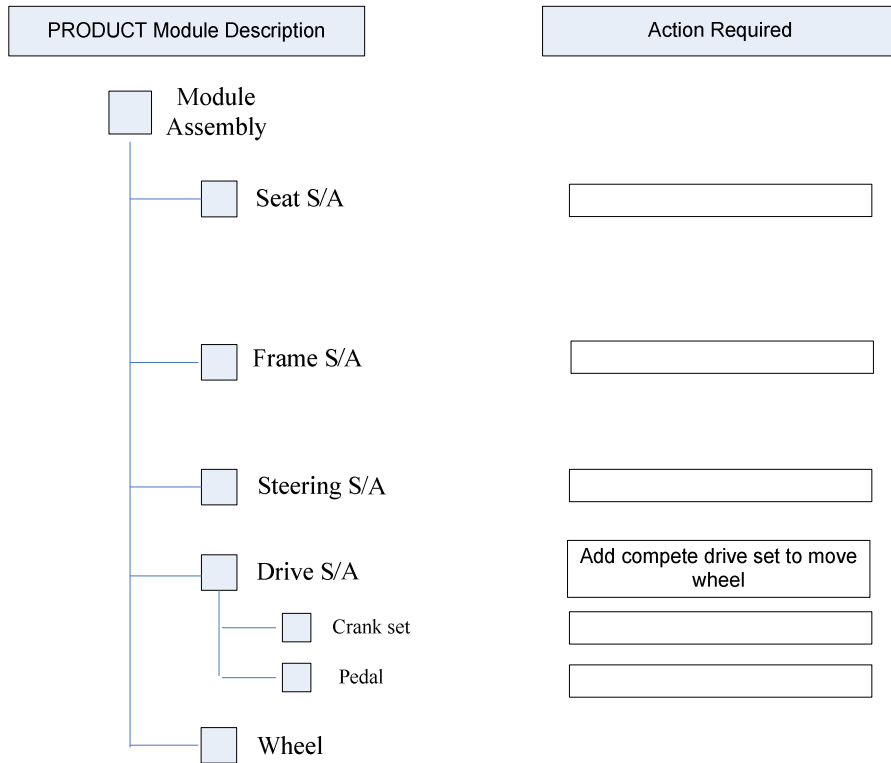

Figure 5.17: User Interface to specify the adding of a drive set to the wheel module

(b). Action Taken

1. Remove the drive module Sub-Assembly complete.

2. Selected the complete drive module sub-assembly from the main module library as replacement

3. Drag the selected module from the library to the product point

4. Bring the selected tub to the assembly position to complete the replacement step

SYSTEM EXECUTION OF USER'S COMMAND

System: to remove the drive module sub-assembly

   i.   Remove the mating condition between the crank arm of drive S/A and frame S/A

System: add the complete replacement drive set module to the product assembly

   i.   Check the module mating and attachment type for the module surfaces between the drive set module and the frame module. *"Mating possible, then proceed to next phase".*

   ii. Attach module together and create constraint and mating condition between the drive set module and the frame module. *"Module attached and constraint created".*
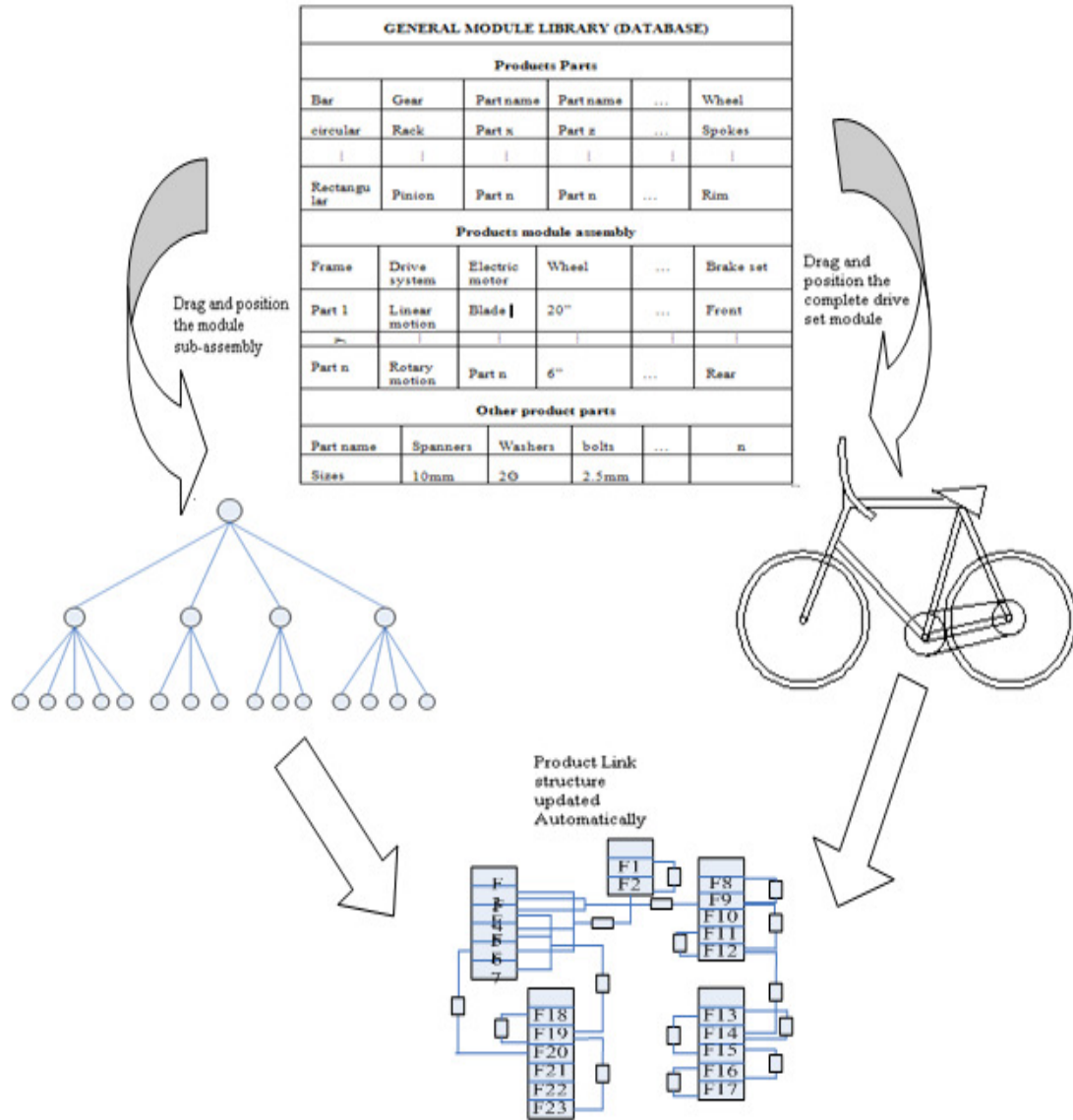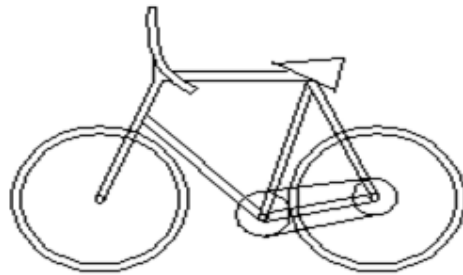
Figure 5.18 shows the user interface for the step.

Figure 5.18: User Interface Showing the coupling of the Drive Set Module to the Product.

STAGE 4: Accept the result or Re-modify

The result is displayed on the product user interface as shown in figure 5.19. Modification accepted by the user and saved.

Figure 5.19: User Interface Showing the New Customer Product.

However, if for instance the final product is not what the customer/user wanted, as it was stated earlier in the previous chapter, by clicking on the re-modify command will prompt the user to repeat stage 3 again. And if still no feasible modification is achieved (that is, the user is not satisfied with the modified product), the system prompts him/her to exit and re-start the process again.

5.4 Concluding Remarks

In this chapter, discussion has been based on the evaluation of the CLD System. The evaluation was based on generating a complex product code from the user and modifying a simpler product into a complex product. As a case study, the user defined a bicycle and the closest match in the database was an exercise bike which had to be modified into a bicycle. The similarity index was generated using a traine NN.

The result was based on the input supplied and the training of NN using some of the product's attributes. From this result, it can be said that the CLD system achieved one of its objectives. The only limitation known was that the NN when used for five product attribute codes could not analyse the result until a large amount of product codes were used.

Also, the second phase which was the fourth step was the modification step. The modification was carried out based on the stipulated stages. Although the step was done manually but when programmed, it will give the same result as the first work.

CHAPTER SIX
CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

This project is focused on carrying out a feasibility study on customer-led conceptual design. The developed system is intended for customers who are not experts in design to be integrated into the design process as co-designers by defining, configuring, matching, or modifying a product to their needs. The focus of this work can be summarised as follows:

- The research presented a new way of integrating customers as co-designers.

- An easy to use system by non-technical personnel is developed. The user interface allows the user to see the process of modifications as the work progresses at all stages. It also provides extensive help for the user.

- Hybrid products and product families are implemented. The CLD system provides the user with access to varieties of products families that are hybrid in nature.

- An example of using the developed CLD System is shown. It presents all stages in detail for modifying a product similar to one specified by the customer.

- Advanced methods such as Customisation, Group Technology, Retrieval Systems and Artificial Neural Networks that have been applied successfully in this research have been presented. An extensive literature review of using these methods is also given.

6.2 Contribution of the Thesis

In this work, a hybrid classification system, a mechanical design coding system, similarity retrieval system and artificial neural network have been used to meet the

challenges of customers in designing their desired product(s). The work presents a number of features which are not available before when it comes to customers and product designing. These are as follows:

- Although there exist some paradigms that allow certain limited involvement of customers in the product development process, this thesis introduces a novel idea of allowing a non-professional customer to become a co-designer of his/her own product.

- As opposed to commercially available coding systems that only deal with individual parts, in this thesis a new classification system for entire products and product families is developed. It has a hybrid architecture combining a hierarchical and chain-type structure. This allows the classification of a large number of products with reasonable simple codes and offer greater flexibility for modifying and expanding the system. The coding system also facilitates group technology developments.

- The thesis presents a novel system for automatic generation of similarity indexes of products based on a wide selection of attributes. It is based on a trained artificial neural network (ANN). The input parameters of the ANN are the codes of two products to be compared, and the output calculates the similarity index between these products. The system enables generating similarity indexes of products previously unknown to the system.

- The thesis presents a novel idea of modifying existing products to meet the specifications of the product specified by the customer. It utilises an automated update of the internal structure of the product based on parts and subassembly databases, link structures, assembly hierarchies, mating conditions and part transformation matrices. The system enables automatic compliancy check at each stage of the modification process. It enables the creation of new products from existing ones by either simplifying a more complex product or by building up a complex product from simpler ones.

6.3 System Limitations

There are certain limitations of the developed system. Since the CLD system at this stage is limited to conceptual design only, it is restricted by the following:

- The system cannot handle any 3-D products but only applicable to 2-D products.

- Complex Product(s) with various materials compositions cannot be designed through this system.

- The system only permits the modification of an existing product which may result in a new design but not creating a new product from scratch.

- The customer does not have direct access to update the Product Module Library.

6.4 Future Work

The following areas could be considered as the main areas for future work.

- **Enhancing the Modification Step**

  Further improvement could be undertaken on the modification step. For instance, the use of CAD with parametric, variational modelling is recommended to allow for detailed design.

- **Development for Commercial Purpose**

  The developed system can be made into a commercial software package either as a stand-alone system or as an additional module to an already existing CAD system.

- **Improving User Friendliness of the CLD**

- **Improving the Product Chain Structure**

  Further work can be done to enhance the product chain structure of the CLD system as follows:

  - More attributes can be added to the hybrid system to give more options in defining the product features.

  - Attributes for both external and internal motions can be improved

- The function-based application attribute can be expanded to accommodate more sub-groups which would allow the specification of more products.

PUBLICATIONS OF ADEYINKA O.M. ADEOYE

1) Adeoye, A. and Szécsi, T. "Design classification system for customer-led design", Annual Scientific Conference, Rousse, Bulgaria, November 8-10, 2007.

2) Adeoye, A. and Szécsi, T. "An Introduction to Customer-Led Design For Mechanically Oriented Products", Proceedings of the 18th International Conference on Flexible Automation and Intelligent Manufacturing, Skövde, Sweden, June 29th- 2nd July, 2008, vol.1, pp. 436-442.

3) Adeoye, A.O.M., Hoque, A.S.M., and Szécsi, T., "The Principle of Customer-Led Design System for Mechanically Oriented Products", *Proceedings of International Conference on Advance Manufacturing and Automation, INCAMA 2009, Tamil nadu, India, March 26-29, 2009.*

4) Adeoye A.O.M, and Szécsi T. "Classification, Coding and Retrieval of Mechanically Oriented Products Using Customer-Led Design Systems", *Proceedings of the 19th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM 2009, Middlesbrough, UK, July 6-8, 2009*, pp. 1277-1285.

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APPENDIX A

The main purpose of using the artificial neural network in this study is to be able to validate the manual process used to retrieved similar product codes from the product database of the system. The evaluation of the weighing factor is essential to this study, because it shows that the research is heading in the right direction.

Below is the result generated when the product attributes codes where entered as input. The summary of the procedure is as follows:

For the following data, the result is shown below

/* ---------------------- PARAMETERS.TXT ------------------------ */

/* Data file for the Customer-lead design project's NN system. */

/* -- */

/* --------------------- Common Processing Parameters --------- */

INPUTS   34

EXAMPLES   609

/* ----------------- Input/Output Intervals ------------------- */

INPUT_0 0 4

INPUT_1 0 3

INPUT_2 0 3

INPUT_3 0 3

INPUT_4 0 3

INPUT_5 0 2

INPUT_6 1 3

INPUT_7 0 3

INPUT_8 1 4

INPUT_9 1 4

INPUT_10 0 8

INPUT_11 1 2

INPUT_12 1 2

INPUT_13 1 3

INPUT_14 0 2

INPUT_15 1 5

INPUT_16 1 6

INPUT_17 0 4

INPUT_18 0 3

INPUT_19 0 3

INPUT_20 0 3

INPUT_21 0 3

INPUT_22 0 2

INPUT_23 1 3

INPUT_24 0 3

INPUT_25 1 4

INPUT_26 1 4

INPUT_27 0 8

INPUT_28 1 2

INPUT_29 1 2

INPUT_30 1 3

INPUT_31 0 2

INPUT_32 1 5

INPUT_33 1 6

OUTPUT   0   100

/* --------------------- Neural Network Parameters ------------ */

HIDDEN_NODES   34

MAX_TOTAL_ERROR   0.001

LEARNING_RATE   0.2

MOMENTUM_TERM   0.2

RANDOM_RATE   0.1

ITER_RESULT_NN   1

ITER_STOP_NN   10000000

Results of recalling examples-------------

Ex[0]:   Inp[0]=1.000000   Inp[1]=1.000000   Inp[2]=2.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=3.000000   Inp[7]=0.000000
Inp[8]=2.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=33.000000
Calc.OUTPUT=33.018326 Diff=-0.018326

Ex[1]:   Inp[0]=1.000000   Inp[1]=2.000000   Inp[2]=2.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=3.000000   Inp[7]=0.000000
Inp[8]=2.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=33.000000
Calc.OUTPUT=32.971058 Diff=0.028942

Ex[2]:   Inp[0]=2.000000   Inp[1]=2.000000   Inp[2]=2.000000   Inp[3]=2.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=2.000000   Inp[7]=2.000000
Inp[8]=2.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=2.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=2.000000
Inp[16]=5.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=32.000000
Calc.OUTPUT=31.985394 Diff=0.014606

Ex[3]:   Inp[0]=2.000000   Inp[1]=2.000000   Inp[2]=2.000000   Inp[3]=2.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=2.000000   Inp[7]=2.000000
Inp[8]=2.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=2.000000
Inp[16]=6.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=32.000000
Calc.OUTPUT=31.999449 Diff=0.000551

Ex[4]:   Inp[0]=3.000000   Inp[1]=1.000000   Inp[2]=0.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=2.000000   Inp[7]=2.000000
Inp[8]=2.000000   Inp[9]=3.000000   Inp[10]=5.000000   Inp[11]=1.000000
Inp[12]=2.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=5.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000

Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=27.000000
Calc.OUTPUT=26.999432 Diff=0.000568

Ex[5]:   Inp[0]=1.000000   Inp[1]=2.000000   Inp[2]=1.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=3.000000   Inp[7]=0.000000
Inp[8]=3.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=25.000000
Calc.OUTPUT=25.022436 Diff=-0.022436

Ex[6]:   Inp[0]=1.000000   Inp[1]=3.000000   Inp[2]=3.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=3.000000   Inp[7]=0.000000
Inp[8]=3.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=25.000000
Calc.OUTPUT=24.993320 Diff=0.006680

Ex[7]:   Inp[0]=1.000000   Inp[1]=1.000000   Inp[2]=3.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=3.000000   Inp[7]=0.000000
Inp[8]=3.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=25.000000
Calc.OUTPUT=24.992262 Diff=0.007738

Ex[8]:   Inp[0]=1.000000   Inp[1]=1.000000   Inp[2]=1.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=1.000000   Inp[7]=0.000000
Inp[8]=2.000000   Inp[9]=3.000000   Inp[10]=8.000000   Inp[11]=1.000000
Inp[12]=2.000000   Inp[13]=1.000000   Inp[14]=2.000000   Inp[15]=3.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=21.000000
Calc.OUTPUT=21.005358 Diff=-0.005358

Ex[9]:   Inp[0]=3.000000   Inp[1]=1.000000   Inp[2]=0.000000   Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=3.000000   Inp[7]=0.000000
Inp[8]=2.000000   Inp[9]=3.000000   Inp[10]=5.000000   Inp[11]=1.000000
Inp[12]=2.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000

Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=21.000000
Calc.OUTPUT=21.017420 Diff=-0.017420

Ex[10]: Inp[0]=3.000000 Inp[1]=2.000000 Inp[2]=0.000000 Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=3.000000   Inp[7]=0.000000
Inp[8]=1.000000   Inp[9]=1.000000   Inp[10]=0.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=2.000000
Inp[16]=1.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=19.000000
Calc.OUTPUT=19.005447 Diff=-0.005447

Ex[11]: Inp[0]=1.000000 Inp[1]=1.000000 Inp[2]=3.000000 Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=2.000000   Inp[7]=1.000000
Inp[8]=4.000000   Inp[9]=3.000000   Inp[10]=1.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=4.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=45.000000
Calc.OUTPUT=45.016556 Diff=-0.016556

Ex[12]: Inp[0]=1.000000 Inp[1]=2.000000 Inp[2]=1.000000 Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=2.000000   Inp[7]=1.000000
Inp[8]=4.000000   Inp[9]=3.000000   Inp[10]=1.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=4.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=14.000000
Calc.OUTPUT=13.981809 Diff=0.018191

Ex[13]: Inp[0]=1.000000 Inp[1]=3.000000 Inp[2]=3.000000 Inp[3]=0.000000
Inp[4]=0.000000   Inp[5]=0.000000   Inp[6]=2.000000   Inp[7]=1.000000
Inp[8]=4.000000   Inp[9]=3.000000   Inp[10]=1.000000   Inp[11]=1.000000
Inp[12]=1.000000   Inp[13]=1.000000   Inp[14]=1.000000   Inp[15]=3.000000
Inp[16]=4.000000   Inp[17]=4.000000   Inp[18]=1.000000   Inp[19]=2.000000
Inp[20]=3.000000   Inp[21]=1.000000   Inp[22]=1.000000   Inp[23]=2.000000
Inp[24]=2.000000   Inp[25]=2.000000   Inp[26]=1.000000   Inp[27]=0.000000
Inp[28]=2.000000   Inp[29]=1.000000   Inp[30]=2.000000   Inp[31]=1.000000
Inp[32]=3.000000   Inp[33]=1.000000   Desired   Output=14.000000
Calc.OUTPUT=14.036686 Diff=-0.036686