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Terminology and Applications

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Contributors

Emilia Sabau, Khadija Tahera, Chris Earl, Musa Gambo K.K., Izabela Kutschenreiter-Praszkiewicz, Imane Bouhaddou, Jinxia Cheng, Razvan Udroiu

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Meet the editors

Dr. Razvan Udroiu is Associate Professor of the Manufacturing Engineering Department and has served as Head of Aerospace Engineering at Transilvania University of Brasov, Romania, since 2009. He attained a BSc degree (5 years) in Aerospace Engineering in 1995 and an MSc degree in Mechanical Engineering in 1996 at Transilvania University of Brasov. He obtained his PhD (Cum Laude) in Industrial Engineering from the same university in 2003. R. Udroiu is author/ coauthor of nine books and more than 60 research papers within journals and international conferences. He has participated in 13 research projects with companies and 14 research/ development/innovation grants. His main skills are related to the fields of additive manufacturing, computer-aided design and manufacturing, advanced manufacturing technologies, composite materials technologies, and aircraft and helicopter engineering.

Dr. Paul Bere is Associate Professor of the Manufacturing Engineering Department, Technical University of Cluj-Napoca. In 2009 he obtained a PhD in Engineering Sciences. In the Department of Manufacturing Engineering at the Faculty of Machine Building he teaches the following subjects: basic manufacture of plastic and composite parts, manufacturing of plastic and composite parts, innovative manufacturing technologies for rapid development products, rapid prototyping technologies, CAD molds, rapid manufacturing, and sustainable development products. He has accumulated over 36 years of experience in the field of composite materials. Since 1999 he has worked with several companies in the field of motorsport such as Formula 3, DTM, Formula 1, and World Endurance Championship Le Mans Series P2 and P1. He has collaborated with Jordan F1, Midland, Spyker F1, Force India F1, HRT F1, and Lotus.

Contents

Preface

The aim of this book is to present the terminology, applications, trends, and developments in Product Lifecycle Management (PLM). PLM is one of the four approaches used as enterprise business information technologies, the others being Enterprise Resource Planning, Customer Relationship Management, and Supply Chain Management. PLM is a business strategy for managing the entire lifecycle of products. This strategy includes the management of conception, design, testing, prototyping, manufacturing, process planning, quality control, use, maintenance, disposal, and recycling of products, integrating people, methods, CAx tools, processes, documentation, and data management solutions.

This book has a total of seven chapters. The introductory chapter is focused on the fundamental and future terminology used in PLM. The next two chapters treat different aspects regarding product design and development. Configuration of the customized product is presented in the fourth chapter. Product testing plays an important role in PLM. Thus, some aspects regarding product testing are presented in the fifth chapter. PLM for supply chain optimization is treated in the next chapter. End of product life is the last stage of the product lifecycle, including the recycling of materials. The last chapter presents an application focused on the recycling of polymeric composite materials.

Dr. Razvan Udroiu
Associate Professor
Department of Manufacturing Engineering
Faculty of Technological Engineering and Industrial Management
Transilvania University of Brasov
Brasov, Romania

Chapter 1

Introductory Chapter: Product Lifecycle Management - Terminology

Razvan Udroiu and Paul Bere

Additional information is available at the end of the chapter

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1. Introduction

The enterprise business information technology (IT) domains include four main management approaches [1, 2]: **product lifecycle management** (PLM), **enterprise resource planning** (ERP), **customer relationship management** (CRM), and **supply chain management** (SCM). The ERP goal is achieving the best enterprise resource utilization. This system enables companies to plan their manufacturing processes and control all aspects of manufacturing including inventory, purchasing, process planning, warehousing and delivery, human resources, finance, etc. SCM system is focused on the supply chain, having the main goals the design, planning, execution, control, and monitoring of all aspects related to storage and distribution. Customer relationship management (CRM) is an approach to manage a company's interaction with current and potential customers [3].

PLM is a business strategy for managing the entire life cycle of products. This strategy includes the management of conception, design, design validation and simulation, prototyping, manufacturing, quality control, use, maintenance, and disposal of products, having integrated people, methods, CAx (computer-aided technologies) tools, processes, documentation, and data management solutions. PLM is a digital paradigm, products being managed with digital computers, digital information, and digital communication [4]. The main benefits of a PLM system implementation in companies are faster time to market, improved productivity and collaboration, better product quality, decreased cost of new product introduction, reduced prototyping costs, improved design review and approval processes, identify potential sale opportunities and revenue contributions, maximize supply chain collaboration, and reduce environmental impacts at the end of product life.

2. Products diversity

Standard living increase of the population has led to the development of new materials and unique services. Those services were hard to be guessed in the past. The diversity of the products is different from one domain to another. All this requires a rigorous planning on waste and resource management in order to obtain some products or to recycle them after end life. The arising problems caused by technological development have begun to affect the life of our planet. This fact has led to the emergence of management measures and decision-making on emerging issues related to the use of this kind of materials, resources, environmental pollutions, and recycling of end-life products.

The world's increasing production has led to the use of special materials [5, 6] as composite materials and smart materials. These have been created and adopted to solve a number of industry production problems, to replace the traditional materials used for manufacturing process of the products. These were created to improve physical and mechanical properties and were developed to solve the production industry problems.

There are different kinds of products on the market. There are different approaches in the word regarding the classification of the products in the world. An approach can be made following their complexity. We can say that there are simple products, or complex ones, which are assembled by another product. From the point of view of materials which is embedded in products, we can say that some products are from a single material, from two, or from many constituents. From the recycling point of view, at the end of the products' life, the products which are made by a single material are easier to be managed. Unfortunately, these products represent a small percentage of the diversity of existing products. Today the materials' constituents are very vast, and the constituents of the products are composed of many chemical substances. These are combined in order to achieve, at the end, a material with custom properties for certain products.

Another type of the products is represented by a large used, a **product in great demand**. These types represented in generally the goods, which integrate more options to use. The beneficiaries of them have the possibility to have more devices integrate in a single one. From PLM point of view, each of the extra options is traded like single one, and all are integrated in a single one. An example of this can be the smartphones or smarts TVs. Each of them is designed for a specific function, to communicate or to watch and get some information. At the same time, we benefit from clock, internet access, calendar, games, and many programs that help us. Also, it is observed in an abundance of mechatronic products on the market. These products contain mechanical, electrical, electronic, and software components.

Another type of the products is represented by **customized goods**. These are customized for each individual customer. They must meet certain specific personalized requirements. In general for these types of products, the cost price is higher, manufacturing time is increasing, and life cycle is bigger.

Nowadays, the life of the products has been getting shorter. This is due to technological progress and the requirements of today's demanding market. The life of the products decreases because new products appeared and those have replaced the old ones quickly.

Passing on to the **complex products** that include a large variety of materials, from PLM point of view, the situation is more complicated. The recycling and the managing of the end life of products are a challenge. We can ask ourselves which will be the costs of a product in reality, if the recycling costs at the end life of the product are bigger than production costs.

The diversity of industrial products is a very vast domain and includes embedded materials, the products themselves, the equipment that led to their fabrication, the resources used, the auxiliary substances, and materials that contributed to the technological process.

3. Product life cycle

The product life cycle includes three main stages: **beginning of product life (BOL)**, **middle of product life (MOL),** and **end of product life (EOL)**. These stages consist of processes which create the PLM process flow.

BOL is the most complex phase of the product life cycle including conceive, design, prototyping, testing, development, production process elaboration, and manufacturing of the product.

In the second phase of the product life cycle, MOL comprises distribution/sales, product use of the final customer, maintenance, repair, and overhaul (MRO) of the product.

End of product life is the last stages of the product life cycle. This stage includes retire, disposal, and recycle of the product.

4. Product lifecycle management

According to the CIMdata Inc. [7], “Product Lifecycle Management is a strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information” [7]. Integrating people, processes, business systems, and information, PLM supports the extended enterprise [7]. The extended enterprise is a wider entity that includes the customers, the employees, the suppliers, the distributors, etc., who collaborate in the design, development, manufacturing, and delivery of a product to the end user. The PLM concept is focused on six important concepts, as follows: strategic business approach, phases of product life cycle, collaboration within the extended enterprise, unique and timed product data source and consistency, traceability, and long-term archiving [8].

Product lifecycle management for “X field” is a general term to define a type of management within a specific field of work, for a specific product. “X field” is a generic term that is related to a specific industry. Thus, different products require different process developments, resulting the following: PLM for aerospace and defense; PLM for the automotive industry; PLM for the construction industry; PLM for the consumer and retail industry; PLM for the energy, process, and utility industry; PLM for the fashion industry; PLM for the food and beverage industry; PLM for the industrial equipment industry; PLM for the life sciences industry; PLM for the marine and offshore industry; PLM for the oil and gas industry; and PLM for the telecom and electronics industry.

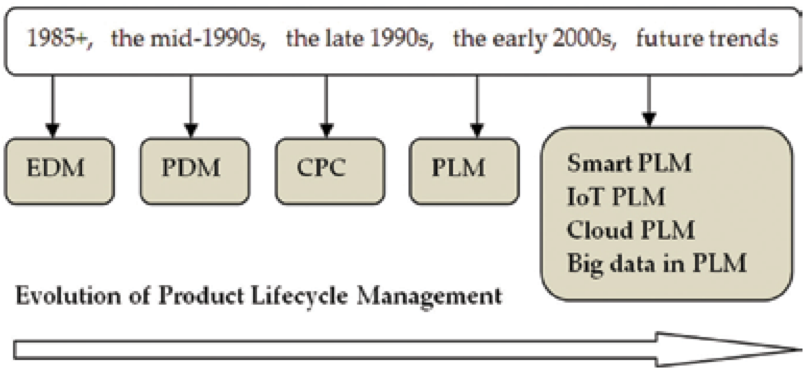

Figure 1. The evolution of the concepts related to PLM.

The evolution of the concepts related to PLM is shown in **Figure 1**. PLM concept was developed based on product data management (PDM). **Product data management** is the business function often within PLM that is focused mainly on design, manufacturing, and engineering data having the purpose of the management and publication of product data. PDM is the link between "islands of automation" such as computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM), being a PLM infrastructure. PDM system provides access and security controls, maintains relationships among product data items, enforces rules that describe and control data flows and processes, and provides notification and messaging facilities [7, 9].

The fundamental terms about PLM are shown in **Figure 2**. Processes, technologies, methods, software tools, and data managed by people are the main fundamentals of PLM that are involved in the lifecycle stages of the product.

Concurrent engineering [10, 11] or **simultaneous engineering** is an approach for product development that integrates all product lifecycle phases and carries out a number of tasks in parallel, minimizing the product development time. One of the most used methods of CE is **design for manufacture and assembly (DFMA)** that integrates two concepts such as design for manufacture (DFM) and design for assembly (DFA). DFM is a design methodology of the parts for their easy manufacturing, reducing the manufacturing costs. DFA is focused on the design of the product for easy assembly, reducing the assembly costs.

Generally, the methods can be classified as follows [12]:

- Methods supporting designers and engineers in the product development stage (e.g., theory for inventing problem-solving (TRIZ, design in context, bottom-up design, top-down design))
- Methods based on past experiences (e.g., design for X) used in BOL, MOL, and EOL
- Evaluation methods of the product responsiveness to needs coming from diverse phases (e.g., risk analysis and failure mode effects analysis (FMEA), fishbone/Ishikawa diagram)

- Management approaches supporting continuous improvement of the enterprise (e.g., just in time, lean manufacturing, six sigma, total quality management, and total productive maintenance)

CAx [4] is a generic term that includes all computer-aided technologies used to process the information and knowledge regarding the product data along the PLM stages. A CAx system is focused on a "X" task, and it contains the following main components: hardware component consisting in computer and interactive devices, software packages, data, knowledge, and human's activities [4]. The "X" task can be product design (computer-aided design) [13–17]; product manufacturing (computer-aided manufacturing) [13–17]; product simulation,

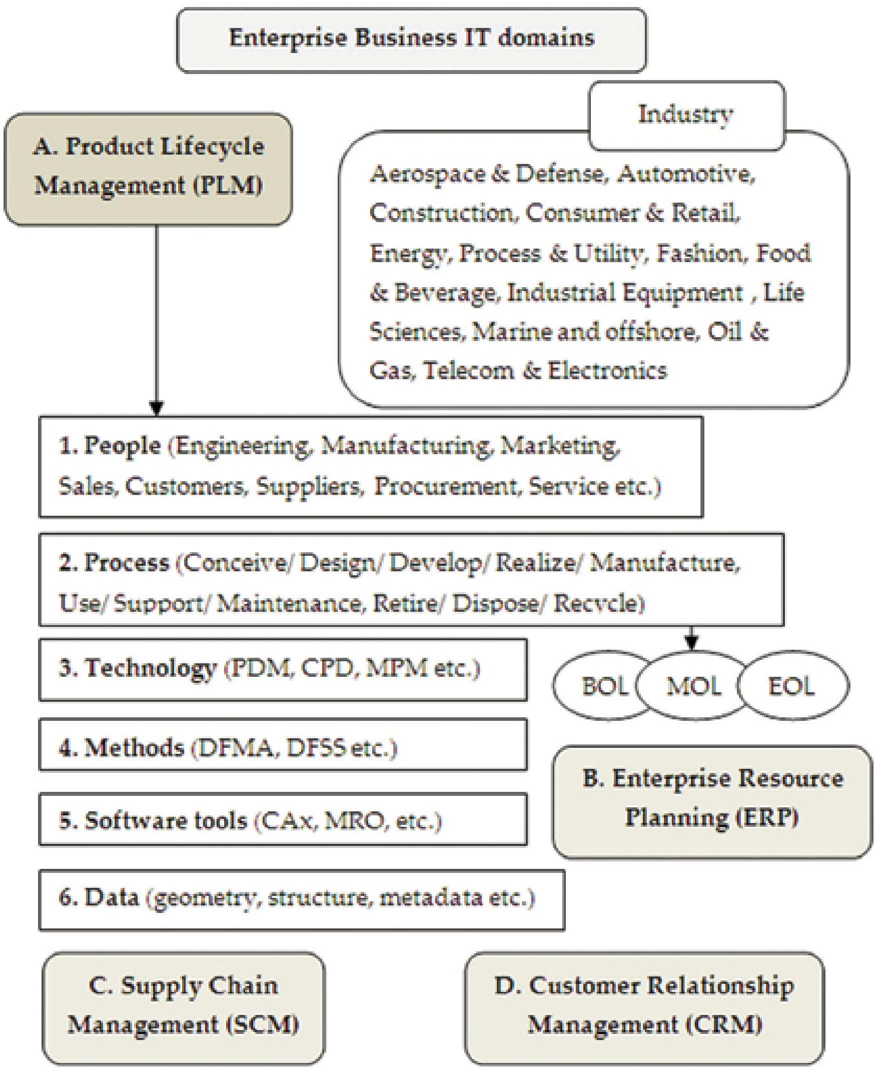

Figure 2. The fundamental terms related to PLM.

Concepts	Remarks
PLM	Product lifecycle management
ERP	Enterprise resource planning
CRM	Customer relationship management
SCM	Supply chain management
EDM	Electronic document management, enterprise data management, or engineering data management
PDM	Product data management
CPC	Collaborative product commerce
PPLM	Product and process lifecycle management
SRM	Supplier relationship management is analogous to customer relationship management
MPM	Manufacturing process management
CE	Concurrent engineering
CPD	Collaborative product development
DFMA	Design for manufacture and assembly
DFSS	Design for six sigma is a business process management method related to traditional six sigma, based on the use of statistical tools
NPD	New product development
Standards of PLM	STEP, DXF, IGES, XML, UML
Virtual enterprise (VE)	Virtual enterprise consists in "a group of people who work together on a project, communicating mainly by phone, email, and the internet, rather than regularly going to a central office to work providing operations as competitive as those in a traditional enterprise" [4, 21]
Digital mock-up (DMU)	Digital mock-up is a concept that allows the description of a product, usually in 3D, for its entire life cycle [4]
Digital manufacturing (DM)	DM links digital product development, digital production planning, and digital facility planning [22]. DM is a manufacturing process in a virtual environment working with digital features (tooling, machining, assembly lines, resources, ergonomics, and factory layout)
Digital factory (DF)	Digital factory consists in a digital mock-up of the factory

Table 1. Terms connected to PLM.

analysis, and optimization (computer-aided engineering); product process planning (computer-aided process planning, CAPP) [11, 14–17]; product quality assurance (computer-aided quality, CAQ); etc. CAE tools are available for a wide range of analyses: finite element analysis (FEA), computational fluid dynamics (CFD), kinematics and dynamic analysis of the mechanisms, etc. The numerical control (NC) of the machine tools and programming of industrial robots that perform tasks as assembly, welding, etc., are the most known applications of CAM.

Also, new technologies such as rapid prototyping (RP), additive manufacturing, and reverse engineering play an innovative role, especially in the BOL phase [18–20].

The main terminology connected to PLM is presented in the **Table 1**.

Digital factory is the foundation of the factory of the future, "a comprehensive approach of network of digital models, methods, and tools—including modeling, simulation, and 3D/virtual reality visualization—integrated by a continuous data management" [23]

New opportunities and future trends for PLM (**Table 2**) have appeared in areas such as **big data**, **smart products**, the **Internet of things**, **knowledge management**, and **SMAC** (social, mobile, analytics, cloud) [30]. **SMAC** is driving business innovation, being a concept that converges of four technologies, social media platforms, mobile technologies and platforms such as the iPhone/ iPad, data analytics, and cloud computing. Cloud computing is one of the key enablers for advanced manufacturing supporting not only storage of product data but also retrieval and reuse of product and process knowledge.

Future concepts	Remarks
Factory of the future/ smart factory	Factory of the future [4, 24] is the combination of "virtual" and "real" that "can self-optimize performance, self-adapt to and learn from new conditions in real or near-real time, and autonomously run entire production processes" [25]
Industry 4.0	Industry 4.0 [26, 27] supposes the introduction of the Internet of things and services into the manufacturing environment [4]
Cloud computing	Cloud computing store, manage, and process data, rather than a local computer by using a network of remote servers hosted on the Internet [4]
CMfg (cloud manufacturing)	Cloud manufacturing [28] uses cloud computing, the Internet of things, service-oriented technologies, and high-performance computing for solving manufacturing applications
Industrial Internet	The industrial Internet "is the integration and linking of big data, analytical tools and wireless networks with physical and industrial equipment, or otherwise applying meta-level networking functions, to distributed systems" [27]
IoT (Internet of things)	The Internet of things comprises of an intelligent interactivity, via the Internet, sensors and actuators, etc., between human and things to exchange information and knowledge
Big data in PLM	"Big data represents the information assets characterized by such a high volume, velocity and variety to require specific technology and analytical methods for its transformation into value."[29]. Big data challenges include capturing data, data storage, data analysis, search, sharing, transfer, visualization, querying, updating, information privacy, and data source
IoT PLM	Big data and the IoT work in conjunction. Data extracted from IoT devices provides a mapping of device interconnectivity
PLM for digital factory (PLM 4.0)	PLM system within the Industry 4.0
Cloud PLM	The applications of cloud computing in PLM
Smart PLM	PLM system for a smart factory

Table 2. Terms connected to the future PLM.

5. PLM software

On the market today, there are several software solutions for PLM implementation. The most known solutions are offered by dominant players such as **Dassault Systèmes** (ENOVIA™ PLM Software), **Siemens** (Teamcenter PLM), **PTC** (PTC Windchill), **SAP Systems, Applications, and Products in Data Processing** (SAP PLM), **Oracle** (Agile PLM), **Arena** (Arena PLM), and **Autodesk** (Autodesk Fusion Lifecycle). **SAP Business Suite** is a collection of integrated applications such as SAP-CRM, SAP-ERP, SAP-PLM, SAP-SRM, and SAP-SCM modules. The most important tools of these software solutions are material management, configuration and change management, design and simulation processes, product planning, project management, document management, deliver projects on time and under budget, collaboration solutions, product quality, and product certification, stocks, and sales management. These tools are increasingly used in large companies, and the offered solutions are customized for different areas of activity. Company databases offer a better management of company resources, of the customers or of suppliers of materials in a timely manner. The PLM software solution increases the companies' productivity, reduces the manufacturing time of the products, and increases the quality. Managing company databases that have workstations in different locations is one of the integrated tools of these software instruments. The companies can manage the common databases, the drawing projects, materials, existing stocks, different stages of product development, as well as the marketing and distribution part or the product phases use throughout their life cycle.

6. Conclusion

PLM systems can manage information across the life cycle of a broad range of products such as manufactured products (airplanes, automobiles, computers, mobile phones, toys, etc.), software product, utility distribution networks (telecommunications), facilities (airports, harbors, and railway systems), and other products (bridges and highways). In the future, every industrial product will be smart like smartphones. These integrated a series of requirements and needs that, besides the basic solution of the product to meet certain needs, will also have a number of facilities which are not strictly necessary but contribute to the comfort of the beneficiary. All this products' facilities not only make it more attractive but also increase its complexity. Requirements and products are increasingly diversified, all contributing to consumer welfare, as time passes.

Author details

Razvan Udroiu[1]* and Paul Bere[2]

*Address all correspondence to: udroiu.r@unitbv.ro

1 Department of Manufacturing Engineering, Transilvania University of Brasov, Brasov, Romania

2 Department of Manufacturing Engineering, Technical University of Cluj-Napoca, Cluj-Napoca, Romania

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Chapter 2

Product Development and Management Strategies

Musa Gambo Kasuwar Kuka

Additional information is available at the end of the chapter

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Abstract

The chapter seeks to discuss and describe the concept of product from the marketing perspective, how companies come about new product, product development options, and the various strategies available to a company to manage new and existing products. It is a conceptual paper which reviews relevant literatures from various sources. In essence, the proposed chapter will be divided into three main sections. Section 1 will introduce the concept of product, its meaning, and core components from the marketing point of view. It will also contain discussion on the various connotations of the term product, what constitute a new product, and new product adoption. Section 2 will dwell on the options available to a company on how to come up with new products including mergers, acquisition, and licensing, franchising, and proactive new product development. It will also explain the two product development strategies that companies adopt in the market place. The last section will discuss the product management strategies available to a firm either from the product life cycle way or the individual product management strategies or both. At the end, conclusions and the general context of the paper are drawn.

Keywords: product, product development, product life cycle, product strategy, product management

1. Introduction

Let us begin this chapter with a brief overview of the marketing process in order to have a clear understanding of marketing and its relationship with product development and management. By and large, marketing practice is built upon the following process:

1. Conducting research to find out the needs and wants of the customers.
2. Market segmentation, targeting, and positioning.

3. Developing the marketing mix program that consists of taking decision on product, price, place (distribution), and promotion.
4. Implementation of the marketing plan and program.
5. Control and evaluation of the marketing program.

The above process is what is usually referred to as the marketing management process which adopts the marketing concept philosophy. This is built on the notion of finding out the needs and wants of the customers before developing the products to satisfy the identified needs and wants. This goes to show that products are developed to solve any identified customers' problems and not the other way round.

1.1. Definition of Product

Product is one of the four elements of the marketing mix; the other three being price, place and promotion, which are all geared towards serving and satisfying the target market. Companies fix the product's price, promote and distribute it to the target market. Therefore, a product is the basic element of marketing mix. The word "Product" has several meanings, but it is generally a bundle of satisfaction that customers purchase or patronize in order to solve a problem. In our day-to-day life, we use many goods, such as soap, biro, book, ball, etc.; as well as services like banking transport, healthcare, or legal services. The term product has been defined differently by various authors and authorities in the field. For example, Harry [1] defines a product as the sum of the physical and psychological satisfactions the buyer receives when he makes a purchase. It is thus a tangible and/or intangible attribute that is offered to the market for sales. Other definitions of a product include:

- **i.** "A product is anything that can be offered to a market for attention, acquisition, use, or consumption that might satisfy a want or need: it includes physical objects, services, personalities, organizations, and ideas [2]."
- **ii.** "Product is a bundle of utilities that satisfy the customer's needs and wants, [3]."
- **iii.** "A product consists of the intrinsic features, extrinsic characteristics, and its intangibles associations [1]".

Thus, from the above definitions, a product can be described as anything that is capable of providing solution to a customer's perceived problem whether it is physical or psychological. Therefore, any product that fails to provide the needed solution to a customer is a not a good product. To this end, when a student buys a biro to write test but it fails to write smoothly, it is not a good product; or when you pay for a healthcare service but get poor service in return. So, to a consumer, the product is anything, which satisfies his needs and wants while to a marketer, the product is a bundle of attributes that can bring returns through satisfaction of customers. It is also pertinent to note that in marketing, the concept of a product covers goods, services, ideas, people, places, and organizations except otherwise specified.

1.2. Product features

To understand the concept of a product well, it is pertinent to consider the issue of product features. These features help to give a vivid description of a product and what a buyer is really buying in a given product. The important features of product are:

1.2.1. Tangible features

A tangible product has some physical features that can be seen and handled, such as shape, size, color, weight, etc. It can be touched and its physical presence can be felt. It is made up of materials like plastic, metals, iron, or wood. Products like perfumes, jewelries, and wrist watches are sold in very attractive packages with esthetic appeals.

1.2.2. Intangible attributes

The core aspect of the product such as its performance, quality, dependability, and reliability are often built in the product or service and therefore intangible. These key attributes cannot be seen, but rather can be felt and experienced after using the product or patronizing the service. Some after-sales services, augmented services, and such pure services like tourism, story-telling, consultancy services, and counseling services fall in this category. Here, the organization is selling experiences or feelings.

1.2.3. Association features

Product may have associated attributes to facilitate its identification and acceptance by buyers. Such attributes may be a brand name, package, warranty, credit terms, delivery terms, or payment options. For example, in Nigeria we have brands like Joy, Lux, Royal Foam, Engen, Tantalizers, etc., which depict positive brand associations.

1.2.4. Exchange value

For marketing purposes, every product, whether tangible or intangible, should have an exchange value and should be capable of being exchanged between buyer and seller, based on mutually agreed considerations. This exchange is a function of product value and the asking price. If the buyer feels that the value he is receiving from the product is equal or even higher than the money he is giving out, he feels satisfied and contented. Otherwise, he feels cheated and shortchanged and will most likely not buy it again and may even de-market the product if he gets the chance.

1.2.5. Customer satisfaction

The product should be able to satisfy consumer needs. Satisfaction can be both real and psychological. For example, when we eat food, wear clothes, or take medicines; we get a real satisfaction; whereas, when we buy insurance plan, services of travel agency, or beauty salon, we derive psychological satisfaction.

1.3. Components of a product

In product development discourse, marketers should understand the key components that make up any product, be it a good or service. The import of this is that it will enable companies to know what to incorporate in their product in order to produce a good and acceptable product. Products have three main components; the core, tangible, and augmented services.

1.3.1. Core product

The core product constitutes the unique selling propositions of the product or service. It connotes the key benefits that a customer is looking for in a given product. Core product provides satisfaction to the customer, thereby becoming the main reason for producing and buying the product. It is an intangible attribute that is built in the product. For example, the core of a robot is performance through artificial intelligence; that of aspirin is pain relief, while the core of a school is imparting knowledge.

1.3.2. Tangible product

This is a product component that can be seen, touched, and identified. In most cases, it is the tangible product that makes the core product tangible and ready for repeated purchases, especially packaging, brand names, marks, or symbol and distinctive coloring. For example, the colors of Chelsea and Manchester football clubs of England are blue and red, respectively.

1.3.3. Augmented product

This is the support package that completes a total product offering such as after-sales service, warranty, delivery, and installation. At this level, the marketer prepares an augmented product that seeks to exceed customer expectations. For example, the hotel can include remote-controlled TV, 24/7 free Wi-Fi internet service, fresh flower, room service, and prompt check-in and checkout.

2. New product development

Product managers only manage the brands produced and introduced into the market. This goes to show that a company has to first develop a product or follow any legal means to acquire a product in order to sell it to the target market. For this reason, it may not be out of place if we appraise the ways through which a company obtains a product. A company can use any of the following ways to get a product, among others.

i. Merger with other company, such as the one between Nigerian Breweries and Consolidated Breweries, which increases the product portfolio of both companies.

ii. Acquisition of an existing company or brand, such as 7Up and Pepsi; Coca-cola and Limca as well as acquisition of Mainstreet Bank limited from Asset Management Company of Nigeria (AMCON) by Skye Bank Plc.

iii. Licensing rights, such as Nigerian Bottling company makers of Coke under license from Coca-Cola Inc. of USA.

iv. Franchising arrangement, like that of McDonalds or Kentucky Fried Chicken (KFC) throughout the world.

v. Management contracting, as a system of marketing expert services such as coaching and technical advisory jobs. For example, the job of Zidane at Real Madrid or Mourinho of Manchester United.

vi. Leasing, a written or implied contract by which an owner (lessor) of an asset grants another party (lessee) the right to use and possess it exclusively for a specified period of time based on some conditions in return for a periodic rental payments.

vii. Hire purchase option for some specific assets.

viii. New product development option by which the company internally follows certain stages to come up with a new product.

Out of the aforementioned ways of obtaining a new product, the main focus of this section is to discuss the process involved in developing a new product by a company.

2.1. New product development process

New product development (NPD) is a complete process of creating and bringing a new product to market. New product development is the process of exploiting market opportunity by turning it into a product or service available for sale. A good understanding of customer needs and wants, the competitive environment and continuous practices, and strategies to better satisfy the customer requirements and increase their market share regulate development of new products. The notion of new product needs to be explained here. By and large, the newness of a product depends on what the customer or target market consider as new. For this reason, a new product can be an invention (entirely new which does not exist before), innovation (new to the company but existing in the industry), or product modification (changing the package, size, design and other features). There are eight steps involved in new product development namely:

i. Idea generation

ii. Idea screening

iii. Concept development and testing

iv. Business analysis

v. Marketing strategy development

vi. Product development

vii. Test marketing

viii. Commercialization

1. **Idea generation**: It is the act of getting as many ideas as possible. Ideas for new products can be obtained from customers, sales representatives, employees, distributors, company's research and development department, competitors, focus groups, or brainstorming. Lots of ideas are generated about the new product and out of these ideas some are implemented. Idea generation or brainstorming of new product, service, or store concepts usually begins when market opportunities are identified so as to support your idea screening phase.

2. **Idea screening**: It is the process of screening the ideas generated in order to do away with those ideas that are not consistent with the company's objectives and resources. This is with a view to eliminate ideas that are not feasible, viable, and acceptable. Many organizations use different criteria in screening the ideas, but in general, screeners often look at the viability, feasibility, and acceptability of the ideas at hand.

3. **Concept development and testing**: The ideas that pass through the screening stage are then developed into concept on paper stating clearly the marketing and engineering details of the product. In essence, the concept will indicate the target market for the product, its benefits, features, and attributes as well as the planned proposed selling price for the product. Similarly, concept should contain the estimated cost of producing the product and its perceived competing brands in the chosen market. When the concept is developed, it has to be tested by asking a number of prospective customers to evaluate the idea based on its feasibility and marketability.

4. **Business analysis**: This stage of the new product development process is geared toward evaluating the overall cost, sales revenue, and profit potentials of the contemplated product idea. This is achieved through such analysis as industry's market potential, market size and growth rate, sales forecast and demand estimation, as well as the estimated profitability, and break-even point for the target product. The main purpose of this analysis is identifying those ideas that are apparently feasible and financially viable. Ideas that are not viable can also be dropped at this stage.

5. **Marketing strategy development**: The most viable ideas that scaled through the previous stages can be used as good candidates for marketing strategy development. In its basic form, this stage calls for formulating the product, pricing, distributing, and promotion strategies to be used in marketing the proposed products when it is introduced. It is pertinent to note that these strategies should be flexible such that it can be modified to conform to the dynamism of the environment.

6. **Product development**: It is at this stage that the actual or physical prototype of the successful idea will be produced. For example, if a company is producing an auto car it will produce a car prototype-like toy car containing all the features and designs specified in the concept development stage. If it is a service, a complete service package will be developed ready for test marketing.

7. **Test marketing**: Here, the company will test the product (and its packaging) in typical usage situations by conducting focus group customer interviews, dealer research or test it at trade shows to determine customer acceptance or otherwise. The company can use the outcome of the test to make adjustments on the planned marketing strategy where necessary. However, a company has to be extra careful in test marketing its planned new

product in order not to expose it to competitors who can easily see and imitate it to come up with their own version sometimes even quicker and better than the initiator.

8. **Commercialization**: This is the final stage of the development process in which the new product will be launched or born. Once it is introduced, it is no longer under the company's control but that of the market. Here a company has to decide on when, where, and how to introduce the product. The timing of the launch is critical as it can make or mar the product's success. For example, launching a new ice-cream during cold season is a wrong timing. The place or venue of launching should also be strategic and closer to the target market. Similarly, a company has to decide on how it can launch the product. There are two main options here namely waterfall and sprinkler approaches. In waterfall approach, a company decides to commercialize it at once in the whole market, which is, introducing it to the whole Nigerian market at a go for instance. The other option is to launch it gradually from one section to another up to the time that the whole market is covered, thus using sprinkler technique. However, the choice of an option depends on the nature of the market, company's resources and level of competition in the market.

In addition, to make its commercialization successful, a company should produce and place an effective promotion to create awareness after ensuring that the products are adequately distributed throughout the market. This is because it will be counterproductive for a company to promote a product that cannot be found in the market by potential buyers.

Nevertheless, it is important to note that these steps may not be followed religiously as some stages may be eliminated or done concurrently in order to reduce the time that the new product development process takes. There are two types of new product development strategies namely proactive and reactive product development strategies. Most leading companies in the industry see new product development as a *proactive* process, where resources are allocated to identify market changes and seize upon new product opportunities before they occur. Conversely, a *reactive* strategy is adopted by follower and strong challengers in which nothing is done until problems occur or the pioneer company introduces an innovation. And because product development process typically requires both engineering and marketing expertise, cross-functional project teams are usually formed to execute the task. The team is responsible for all aspects of the project, from initial idea generation to final commercialization, and they usually report to senior management or project manager as the case may be. Thus, the path to develop successful new products points out three key processes that can play critical role in product development. They are talking to the customer, nurturing a project culture, and keeping it focused [4].

2.2. New product adoption process

The key to successful new product introduction is its acceptance by the customers and this is determined by the adoption process. Adoption process is a series of stages by which a consumer decides to adopt a new product or service. In today's competitive world, a consumer is faced with a lot of choices from a number of competing products. A consumer often passes through five stages in deciding to adopt or accept an innovation from awareness to adoption. These stages are briefly explained below.

1. **Awareness**: This is the step where major marketers spend a huge sum of money to create awareness about their innovation. This can be done through intensive advertising campaigns, aggressive selling, use of consumer and dealer sales promotion, and e-marketing communication.

2. **Information search**: Following the dissemination of adequate information about the product, buyers in the market will be aware of the product and will look for more information in order to know it better. People search for information from company adverts, dealers, sales agents, and other consumers.

3. **Evaluation**: Here, the prospective buyer uses the information obtained to compare different product features and benefits such as price, performance, quality, availability, or durability. All this is an attempt to make rational decision.

4. **Trial**: It is usually done on products with low unit value and higher degree of divisibility. For technical products and other bigger assets, marketers use demonstration to enhance its trialability. This is, however, difficult in services as services are generally intangible in nature. However, service marketing managers do find ways of offering trial packs to users, but it is easier in product marketing through sales promotional activities like giving out free samples, contests, premiums, discounts, etc.

5. **Adoption**: Based on the outcome of the trial process, this is where the consumer finally decides to adopt the product. It is expected that the customer will continue to buy the product repeatedly based on the satisfaction he/she derives from using the product or service. Otherwise, the process might end in rejection.

2.3. Product life cycle and its stages

Products are like human beings, they spend their life in the market. Some stay longer in the market, while others have a shorter life span. However, unlike human beings whose life is in the hands of God, the life of a product is controlled by the company and its market. It depends on whether it is adopted or rejected by the target market. Therefore, because companies know that the products they sell all have a limited lifespan, majority of them invest heavily on new product development in order to make sure that their businesses continue to grow. By and large, the product life cycle has four very clearly defined stages, each with its own characteristics [4]. These stages are introduction, growth, maturity, and decline stage (**Figure 1**) [5].

Introduction Stage: Once a product is launched in the market, it enters into the introduction stage. This is the first stage in an ideal product life cycle. It is characterized by high promotion and intensive distribution especially for fast moving consumer goods (FMCG). These marketing activities often lead to increase in costs at the initial stage particularly for a company with a pioneering status which has to spend a lot to create awareness. It is at this stage that the product is formally born and it enters the competitive field in the market. This goes to show that once in a market, the product's life is determined by the market forces and the ability of the company to manage the product successfully in the market. Thus, if the product is accepted in the market, it will attract other competitors to the market if the market has no

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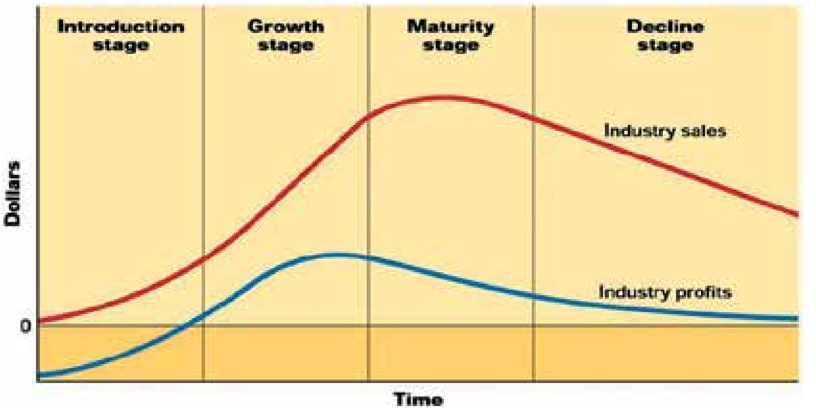

Figure 1. Product life cycle stages. Source: [5].

or low entry barriers. Otherwise, it may even die at this stage. This happened with Fanta blackcurrant soft drink brand of Nigerian Bottling company makers of Coca-cola which died immediately after introduction.

Growth stage: The growth stage is the next phase of the "S" shaped product life cycle. The growth here means increased sales of the product because it is widely accepted by the target market. As the sales rise, the market will also grow and revenues will now upset the initial cost of developing and launching the product resulting to profit generation. To maintain the growth momentum, a company has to emphasize brand preference in its promotion rather than brand awareness.

Maturity stage: When sales stabilize and market is saturated the maturity stage sets in. This is probably the most competitive time for most products and businesses. Companies here need to consider the strategy of product modifications, market expansion, or marketing mix modification, which might give them a competitive advantage. The aim here is to get more customers for the product. Organizations usually like to maintain their products in this stage in order to enjoy the cash inflows from the market, but it is very difficult to manage.

Decline stage: This stage is characterized by steady decrease in sales and profit in the market. This may be because the product has lost its appeal with the customers or presence of better products in the market or the product becomes obsolete, and therefore needs further improvements. Companies do not like this stage because of its adverse consequences and will do everything possible to avoid it. However, for some products this stage is inevitable, and as a result, measures should be put in place to either resuscitate the product or phase it out of the market. In general, the main objective of the product life cycle stages is to enable product managers to know how they can enhance the performance of the products within the context of the company's business strategies [6].

2.3.1. Product life cycle patterns

Some products follow the idealized S-shaped life cycle as explained above, while others follow some patterns depending on how they are managed in the market by the company. This

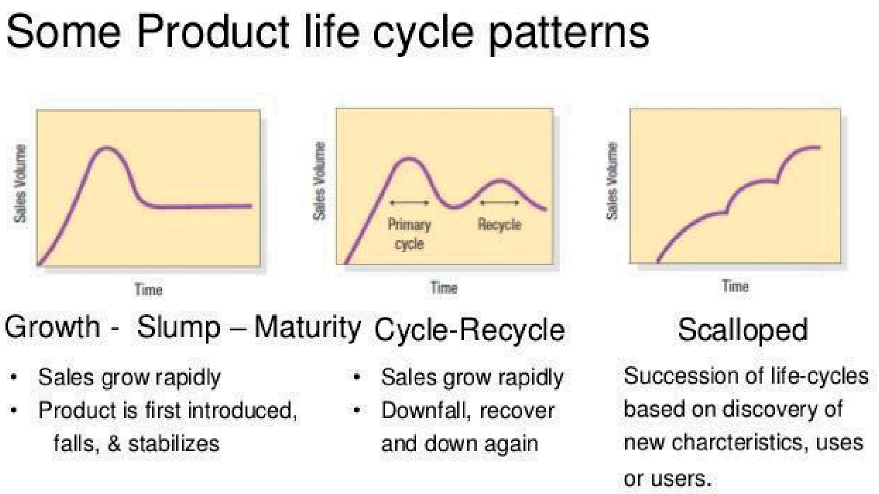

Figure 2. Other product life cycle pattern. Source: [7].

goes to show that product management plays a major role in determining the length of a products life cycle. A product can follow a pattern known as **growth-slump-maturity pattern**. This kind of pattern usually encounters a rapid growth initially but later in the life cycle sales decline with a stabilization at a certain level. One of the examples of such product in Nigeria is the Globacom mobile communication services which experienced a very high sales volume at introduction but slumped down and stabilizes presently.

The **cycle-recycle pattern** depicts a two-phased product life cycle. At the initial phase, a product goes through the ideal stages probably up to decline stage. But after using some strategies to reinvigorate and re-launch the product in the market, it starts another life cycle and depending on how it is managed, it may stay longer or shorter in the market. A good example here is Maclean toothpaste in Nigeria, which went out of the market before it was later re-introduced into the Nigerian market as a new product thus starting a new life cycle entirely.

Another common pattern is called **scalloped pattern**. This is where sales enjoy a succession of growth periods based on the discovery of new product characteristics, uses, or users [7]. Omo and Maggi cube brands in Nigeria show a scalloped life cycle because of the way each of these brands is managed for a long period of time. **Figure 2** illustrates the life cycle patterns.

3. Product management

Product management is a unique function [6]. It is an important area in marketing because it paves the way for sustainable product performance and profitability for companies. Bjernulf and Billgren define product management as "the task that consist of product planning (making sure that the right product is offered), product marketing (enabling the product to reach its potential market), product strategy (the guide for product value delivery over the life cycle), and creating insights (understanding legacy, ecosystems/markets and driving forces)" [8]. Haines and Ausura also define it as a strategic and tactical management of products which are already in the market [6]. In addition, Windley sees product management as the process of designing, building, operating, and maintaining a good or service [9]. From these definitions, it can be clearly seen that product management is all about conceiving, developing, maintaining, and controlling the product sustainably over its life cycle. It deals with deciding on what the product will be and ensuring that it remains like that in the market profitably. Thus, an effective and high performing product management in a nutshell, enables companies to sell what is developed and develop what they can sell.

Similarly, product management can be seen as the act of effective customer life cycle Management. According to Windley, "customer life cycle consists of two phases; customer buying the product and customer using the product," [9]. Here, it is important to add the third stage, which is the decision to discard the product by the same customer. But in product management, companies are always trying to avoid the third stage because it leads to product decline or death in the market. In general, there are two methods of managing a product; the product life cycle and individual product management strategies.

Perhaps a more comprehensive definition of product lifecycle management is the one offered by Razvan Udroiu who views it as "a business strategy for managing the entire lifecycle of products. This strategy includes the management of conception, design, design validation and simulation, prototyping, manufacturing, quality control, use, maintenance and disposal of products, having integrated people, methods, CAx tools, processes, documentation, and data management solutions" [10]. The import of this definition is that product life cycle management can be seen from two different angles; traditional and modern perspectives. The traditional product life cycle management is very conservative and outdated. There is no innovation and creativity in it but rather a dormant, rigid, and stone-age orientation. Traditional farming system, local textiles, blacksmith, cobblers, and pottery especially in some African countries fall in this category. There is no modification or addition of new features but a religious utilization and protection of the past.

The modern perspectives on the other hand deals with the use of modern technology to produce and manage products overtime. There is creativity, innovation, and frequent modifications here which, in turn, lead to the development of many products variants and even new inventions. The application of computer-aided designs (CAD), robotics, drones, internet facilities, and other digital devices fall into this category. The design, manufacture, use and management of airlines services are examples of modern product life cycle management. To remain competitive and relevant in today's market, a company has to adopt the modern perspective of product life cycle management.

3.1. Product life cycle management strategies

The key focus here is to successfully and proactively manage products throughout their lifetime, by applying the appropriate resources and sales and marketing strategies, depending on which stage a product is in the cycle.

3.1.1. Strategies in the introductory stage

The nature and characteristics of the introductory stage have been discussed earlier in this chapter. Therefore, the main challenge in this stage is that when a new product is launched, there is typically small market which translates into low sales. There is high cost associated with research and development, marketing, and promotion. These costs notwithstanding, most companies will see negative profits in this stage with limited competition especially if the product is entirely new in the market.

A company can adopt any of the four product introduction strategies; rapid skimming strategy using high promotion with higher initial price, rapid penetration strategy (involving high promotion with low price), slow penetration strategy (using low promotion with associated lower price), and slow skimming strategy (involving low promotion with higher initial price). Each of these strategies is built upon the objectives of the company of either market penetration or market skimming, i.e., higher profit. This, in turn, depends on how price sensitive the market is. In any case, it is always better to adopt penetration strategy in order to encourage more product adoption which produces higher sales volume.

3.1.2. Growth stage strategies

At this stage, brand managers have to effectively manage the challenge of increased competition as new manufacturers seek to benefit from a new, developing market, and its resultant effects. In response to the growing number of competitors that are likely to enter the market during the growth phase, manufacturers tend to lower their prices in order to achieve the desired increase in sales. Marketers should also change the focus of their promotion from product awareness to brand preference which will help to increase the size of the market and sharp increase in sales.

3.1.3. Strategies in the maturity stage

In product management, this stage can be quite challenging and difficult to manage for manufacturers. In the first two stages, companies try to establish a market and then grow sales to achieve increased market share. However, during the maturity stage, the primary focus for most companies will be maintaining their market share amidst many challenges such as market saturation, decreasing market share, and profits caused by stiff competition.

While the market may reach saturation during the maturity stage, manufacturers might be able to grow their market share and increase profits in other ways. Kotler and Keller opine that market, product and marketing modification are the three broad strategies that can be used to manage products in the maturity stage [2]. Market modification calls for expanding the existing market by getting more users for the product, developing new uses for the product and promoting more usage for the product. For example, for Unilever to encourage buyers of its Close-up toothpaste to use it three times after every meal. This will increase the usage rate and need for replacement. Product features modification involves quality, features and style improvements, and other innovative marketing campaigns to improve market share through differentiation. In the same vein, marketing program on pricing, distribution, advertising, sales promotion, and services can be modified to further stimulate sales and market share for the product. Thus, the main goal here is companies to develop innovative ways to make their product more appealing to the consumer that will maintain, and perhaps even increase, their market share.

3.1.4. Decline stage strategies

The key focus here is to be able to harvest the declining product by offering cheaper products, selling to the laggards' market segment that is the last to adopt an innovation. Firms can also offer discounts and other promotional activities to increase sales in the short run. In the long run, a company can think of entering a new market with the existing product, product modification or even selling the product in foreign market thereby starting a new life cycle entirely. However, poorly managed product cannot withstand the harsh conditions of this stage which gives organization no option other than to phase the affected product out of the market. To do this, a company should establish a product review committee consisting of members from marketing, finance, engineering, production, and research and development to study the performance of a declining product [11]. After the review, the team can then recommend a product or products that can be built through re-investment, those to harvest, hold, or divest from the portfolio. Therefore, decision on phasing out a product should not be taken haphazardly in a rush; rather, it should be based on an informed decision. Consequently, the product life cycle curve needs to be applied with a certain amount of care, even though it is still a useful model which provides businesses and their marketing departments with the opportunity to plan ahead and be better prepared to meet those future challenges.

3.2. Product mix and product-line analysis

It is equally important for companies to appreciate the significance of product mix and product line in the product management discourse. This is because of the relevance of the two concepts in determining the level and complexity of managing a product portfolio. A product mix is the set of all products and items a particular company offers for sale. It is the total product portfolio that a company manages. While a product line is a group of closely related

Retail banking	Corporate banking	e-Business	Private banking
Jaiz saving acct	Jaiz Corporate Acct.	Jaiz Online	Jaiz Premium
Jaiz current acct	Corporate saving	Jaiz Mobile	Investment Acct
Jaiz salary acct	Domiciliary Acct	Point of Sales (POS)	
Jaiz Kids acct	Working Capital acct	Jaiz pay	
Jaiz Tier one acct	Project Financing	SMS Banking	
Jaiz Tier two acct	Real Estate Financing	Jaiz just Top-up	
Personal Finance	Service Lease	Verve cards	
Rental Finance	Import Finance	Master cards	
Medical Finance	Export Finance		
Education Finance			
Jaiz Travel Finance			

Source: [12].

Table 1. Jaiz Bank's product mix.

products that are considered a unit because of marketing, technical, or end-use considerations. In other words, a product line consists of a set of brands that are closely related due to the similar functions they perform, they are sold to the same customer groups, use the same channel of distribution or fall within the same price range [4]. For instance, a personal computer is one product line. An example of a product mix and product line width, length, depth, and consistency for Jaiz Bank Nigeria is depicted in **Table 1**.

A company's product mix has a certain width, depth, and consistency. The width of a product mix refers to how many different product lines the company carries. In the table, Jaiz Bank has four lines of services. Product mix depth is the total number of product items under each line. In **Table 1**, the depth of retail banking line is 11 different services. While the consistency is the degree to which all the products in the mix are related in one or the other. This may be in terms of the market being served, distribution channel used, or common production processes. All the services of Jaiz Bank are consistent in their banking focus. Companies normally develop a basic platform and modules that can be added to meet different customer requirements. This modular approach enables the company to offer variety while lowering production costs.

3.3. Product differentiation

Successful product management cannot be achieved without product differentiation which is a process of designing and formulating unique and meaningful features that provides an identity around company's products. Differentiation can be built around goods or services such as automobiles, furniture, designer shoes, bags, and healthcare services. The aim is to make the target market identify and recognize the difference. If the market perceives no difference between two competing products, then the only possible means of competition is through pricing. In a situation such as this, products are viewed by customers as very easy substitutes for one another.

Products can be differentiated through many different ways. This differentiation may for example take the form of different packaging, marketing and product features, performance, conformance, durability, reliability, reparability, style, and design [2]. As long as a business can come up with a creative way to differentiate its product or service, gaining a competitive advantage is possible.

3.4. Other product management strategies

Apart from the life cycle product management strategies, companies also have an array of specific product strategies to use in managing their product assortments. These, products include, among others, the following:

i. Limited versus full-line product strategy

ii. Line filling strategy

iii. Line stretching strategy

iv. Line modernization

v. Line Featuring

vi. Line pruning

vii. Brand extension strategy

viii. Product repositioning strategy

ix. Planned product obsolescence

x. Product deletion strategy

Limited versus full-line strategy: As the name implies, this strategy simply deals with a company's decision to carry few or many product lines in its portfolio. Small scale enterprises (SMEs) and micro enterprises, for example, manage few products or even one product item based on their size. Companies like Procter and Gamble, Unilever, and Dangote Group carry many product lines and product assortments which make it very complex to manage than just few line or brands. However, it should be noted that companies should not put their eggs in one basket by offering one brand or few lines; rather, they should spread their risks by expanding their product lines.

Line filling: Line filling means adding products to fill a gap in the existing line. It is the process of lengthening the product mix by adding more items within the present range. Reasons for line filling may include getting incremental profits, maintaining dealers who complain about lost sales because of missing items in the line, utilizing excess capacity, becoming a leading full-line company and to keep competitors away. To achieve this, a company can introduce flanker products to protect the main brand from competitors. For example, Nestle Foods Nigeria Plc. has introduced different flavors of Maggi to give protection to Maggi star brand like Maggi chicken, Maggi crayfish, Maggi beef, Maggi pepper soup, etc. However, care should be taken not to introduce a product that will kill or cannibalize the existing product. Charles Schewe argues that the introduction of Classic Coke has cannibalized the sales of regular Coke [13].

Line stretching: This occurs when a company lengthens its product line beyond its current range. This is a frequent measure taken by companies to enter new price slots and to cater for new market segments. The product may be stretched by the addition of new models, sizes, variants, etc. For example, Toyota car comes in different models and brand names such as Carina, Corolla, Camry, Yaris, Prius, and Mirai in order to serve different customer segments. A company can choose to trade up or trade down. Trading up is a situation in which a company known for marketing low priced product will add a high quality brand sold at higher price. For example, Volkswagen traded up from Beetle to Arteon model to serve the upper class. Trading down, on the other hand, is a strategy by which a company that is positioned in the upper market may decide to introduce a lower price line. A company can adopt this strategy to exploit strong growth opportunities in the lower market segment, tie-up lower-end competitors so that they do not move up-market or move out of a stagnating market.

Line modernization: Product lines need to be modernized continuously. Companies plan improvements to encourage customer migration to higher-valued, higher-priced items. For instance, Microsoft has upgraded its Windows operating system from Windows 7 to Windows 8, XP, Vista, and Windows 10.

Line featuring: The product-line manager selects one or few items in the line to feature. Sometimes, a company finds one end of its line selling well and the other end selling poorly. Then, the company may try to boost demand for the low-selling ones that are threatened with extinction due to lack of demand.

Line pruning: This is otherwise called line reduction. At times a company finds that over the years it has introduced many variants of a product in the product line probably because of the changing market situations which makes the product lines become unduly complicated with too many variants. So, when the products are not satisfactorily performing, the product managers need to drop them from the product line. This may lead to increased profitability due to cost reduction from promotion and other marketing expenses. Thus, line pruning is a well thought-out decision by the product manager to drop some product variants from the line.

Product repositioning strategy: First, positioning is the process of placing the product's functionality, relevance, or attributes in the minds of customers. Positioning helps to create a unique perception about a product in the minds of consumers such that a mere mentioning of that brand will evoke an association of quality or otherwise on the product. For example, Mercedes brand evokes good manufacture, McDonald's means quality fast food and snacks, and Singapore Airlines means responsive and reliable airline services. Therefore, a company may decide to reposition its products in order to serve another market segment thereby extending the product's life cycle. For example, Cadbury Nigeria Plc. initially positioned its Bournvita brand as food drink for future sporting champions. But today, it is repositioned as a food drink for child nourishment in their advert slogan "every child deserves nourishment, every child deserves Bournvita." So, repositioning is used in order to add value to the brand to enhance its marketability.

Brand extension strategy: Brand extension or brand stretching is a marketing strategy in which a firm marketing a product with a well-developed image uses the same brand name in a different product category [4]. Companies use this strategy to increase and leverage brand equity (which is the net worth and long-term value of the original brand name) to market a new business or product to a new customer market. An example of a brand extension is PZ's Venus brand which is used to create Venus Soap, Cream, lotion, powder, and hair relaxer. It increases awareness of the brand name and increases profitability from offerings in more than one product category. Another example is Dangote brand which is extended to Dangote cement, Dangote sugar, Dangote salt, Dangote flour, and Dangote transport.

Product standardization versus customization in global market: Customized and standardized marketing strategies are two opposing product management options in international marketing operation. In recent years, there has been an increased urge among local organizations to diversify their operations in the international market to enhance their revenues, competitiveness and global market share. This makes it essential for organizations to adopt international marketing strategies to guard them against foreign competition. Customization strategy is based upon the polycentric orientation of international marketing operation. This ideology holds that due to cultural and other differences among countries, marketing strategies should be tailor made for each country. This strategy is influenced by the differences in buyer behavior characteristics, socio-economic condition, and competitive environment.

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Standardization, on the other hand, is a complete contrast to the customized strategy by which a standard product is produced to serve a homogeneous market worldwide. When there is a convergence of needs due to consumer behavior or socio-economic similarities, a product can be produced to serve these markets anywhere in the world. For example, sporting equipment and products and services such as club jerseys, boots of EUFA Champions league matches are sold to customers all over the world without any modification. Similarly, Sony uses the same packaging across several countries for its Play station product; Coca-Cola has prevailed successfully in the global market while Emirate Airlines adopts the same marketing strategy and services to serve its global markets.

Planned obsolescence: Obsolescence occurs when an object, service, or practice is no longer wanted even though it may still be in good working order. Obsolete is something that is already disused or discarded, or antiquated. Therefore, planned obsolescence is a deliberate strategy which a company employs to purposefully make a product outdated or non-functional within a set period of time, so that customers have to buy a new one. A good example of this is the lifespan of a light bulb which does not lasts longer; one has to keep buying more and more. For planned obsolescence to work, the customer must feel that he has value for money from using the product as well as having enough confidence on the company.

Planned obsolescence is a business strategy in which the life of a product is designed and built into it from its conception. This is done so that in future the consumer feels a need to purchase new products and services that the manufacturer brings out as replacements for the old ones. For instance, fashion of any sort is deeply inclined to built-in obsolescence. Also, the strategy of planned obsolescence is common in the computer industry too. New software is often carefully developed to reduce the value of the previous version in the eyes of consumers. However, a strategy of planned obsolescence can backfire if a manufacturer produces new products to replace old ones too often, which leads to consumer resistance.

Planned obsolescence can be physical, functional, style, and technological obsolescence. Physical obsolescence is a situation in which a product becomes outdated due to the wear and tear of the product. Old products such as refrigerators, car tires, and clothes fall in this category. Functional obsolescence is a reduction in the usefulness or desirability of an object because of an outdated design feature, usually one that cannot be easily changed. Sometimes functional obsolescence is built in the product when designing it. For example, car or cell phone batteries, electric bulb, entry visa and spark plugs, among others. With regards to style obsolescence, whenever a product is no longer desirable to the customers because it has gone out of the popular fashion, its style is considered to be obsolete. It is principally a matter of esthetics and not one of performance or function. The periodic introduction of new models of cars by Honda and Toyota which renders the existing models out of fashion is an example of style obsolescence. While technological obsolescence occurs when a technical product or service is no longer needed or wanted even though it could still be in working order. Technological obsolescence generally occurs when a new product has been created to replace an older version as a result of technological development. For example, the introduction of computer and printer render manual typewriter obsolete, the same thing applies to digital camera and analog camera like Kodak, color and high definition television versus black and white television, and so forth.

Product deletion strategy: Whenever a product is not performing and is not patronized by customers, it is a good candidate for deletion, i.e., deciding to remove or phase out the product from the market. The strategy for deletion can be instant or gradual depending on the fate of the product in the market. If it is consuming money without bringing any return, instant deletion is recommended. But if the product is still bringing some revenue to the company, it can be allowed to die gradually in order to harvest the remaining cash inflows. Alternatively, that product can be withdrawn from its existing market and introduced in another market to start its new life cycle.

4. Case study

To illustrate and validate the foregoing theoretical discussion, a practical product development and management case study is presented here. This is from an earlier published research conducted by the author of this chapter.

Dala Foods Nigeria Limited: Effective Product Development and Management in Foods Processing (Agribusiness) Firm

Introduction

"Dala Foods Nigeria limited is a resilient indigenous food processing company which was incorporated in 1979 and started operation in 1980. Its proactive product development strategy enables it to introduce and manage five unique brands of instant food drinks namely Dala city tea, instant *Kunu*, Diet *Kunu*, dried *Fura*, and *Bisk i* (local couscous). It is this innovative drive that made DALA to be recognized both locally and internationally through many awards that the company won for itself and the country. The fact that the company was and is still able to survive and prosper in the hard business environment of Nigeria shows that agribusinesses have something to learn from this indefatigable company hence the case study.

Company background

Dala Foods Nigeria limited was incorporated as a food processing company with an initial share capital of N400,000 by a visionary and innovative entrepreneur late Alhaji Safiyanu Madugu who served as the Chairman. The Company is wholly owned by Nigerians and it is located in the North Western State of Kano, Nigeria. It started operation in a rented apartment in 1980 with staff strength of 35 members. Today, it employs 135 people in its permanent site at Sharada industrial estate in Kano State with a capital base of over N 100 million and reaching N 250 million turn over annually.

Dala Foods has a well-equipped laboratory manned by qualified and experienced Food Scientist, Technologist, and other laboratory attendants. Its flagship brand, Dala city teabag, is a house hold name in Kano, a state with a total population above nine million (9 m) people, and it has been competing with both local and foreign brands for the past 32 years.

The tea market in Northern Nigeria and Kano in particular is very attractive and viable due to stable demand and high population growth. People in the area always want to drink tea or *shayi* in Hausa language anytime of the day. This opportunity is what attracted local and foreign brands such as Lipton (local and imported), Top tea, Tiger tea, Highland tea, Akbar, and Tea king to the Nigerian market. Another opportunity is the affordability of tea to the mass market. With your N5or N10 you can get one or two tea bags to quench your thirst for a beverage drink.

The market performance of city tea bag is very encouraging. The brand name of Dala city tea emanated from the famous Dala hill in the ancient city of Kano so, it is a well-known brand which made it easier for people to pronounce and remember. But the company did not relent; it launched Dala city tea with aggressive promotion through radio and Television Jingles. In addition, the company sponsored a popular TV Indian film show in the night. Little wonder then that the brand got massive acceptance and from 1980 to 1989 the sales and market share of Dala city grew steadily. Due to population growth and better disposable income, the demand for tea increased and from 1990 to 1999 down to 2010 the sales of Dala city tea made a significant move upward. Dala city tea brand can be considered to be in the growth maturity stage because the company is yet to meet the growing demand of tea in Kano in spite of the increased influx of foreign tea brands.

Following the success of Dala tea, the company introduced instant *Kunun Tsamiya* to the market in 2001. Immediately, the sales of *Kunun Tsamiya*, a Hausa term for Tamarind millet gruel, started to grow and it follows the same trend and even better than that of Dala tea. This is because of the unique nature of the product, and unlike city tea, *Kunun tsamiya* has no identified competitor in the market apart from local unhygienic products from informal businesses that are inherently insignificant. Another key characteristic of Dala's *Kunun tsamiya* is it brings succor to housewives from the chore of dehusking, winnowing, and grinding of millet in the process of making local *Kunun tsamiya*. This process takes more than 5 h to finish in the traditional method, but with instant *Kunu*, the difficulty has been reduced to just 5–10 min! That is why at present, Dala Foods could not adequately meet the demand of the product. This brand is apparently in the introductory stage but moving into its growth stage.

Similarly, the company introduced Diet *Kunu* to serve the market segment of those with diabetics. This is quite innovative and timely because of the sizeable number of diabetic patients in Kano who are largely old and incidentally, consumers of traditional *Kunu*. Diet Kunu is its infancy stage but its demand is increasing due to the rise in the number of diabetic patients in the region. In general, we can confidently say that instant *Kunu* is swimming in blue ocean waters as the only brand of its type in Nigeria presently. Other brands produced and marketed by the company are Instant *Fura* (cooked ground millet) and instant Biski (local couscous). All these brands are adapted household names of some traditional food and beverages that are difficult to prepare but made easy courtesy of Dala Foods.

Moreover, Dala Foods produces another food product called Action Meal – a food supplement for malnourish patients formulated by Institute of Human Virology, Nigeria (IHVN) and processed from Maize, Soya beans and Groundnut on contracts for other global organizations. The company has benefited from those contract productions in form of increased sales turnover and revenue, gaining more experience in other grains processing and availability of ready-made market niche (malnourished children) and easy access to foreign market through donor organizations. Similarly, Dala foods will have the opportunity for free promotion of its corporate identity in all areas served by donor organizations in form of humanitarian aid to malnourished children. All the above products are registered and certified by the National Agency for Foods Drugs Administration and Control (NAFDAC) and Standard Organization of Nigeria (SON).

In all these brands, the company followed the new product development process discussed earlier in this chapter, but albeit not as comprehensive as it should be. This is because the staff that carried out the tasks lacked the required skills and experience as at then. However, Dala Foods is able to succeed in this regard because of its innovative drive and pioneer status. It is this innovative drive that made the Company to win many awards for itself and the country such as the Quality certificate from SON in 1988, Gold medal in 1989 as one of the best product exhibited in Leipzig International Trade Fair, a Global Food Industry award in 2008 from the International Union of Food, Science and Technology (IUFoST) and the Nigeria50 Awards as a fast growing company in 2013 by the Tony Elumelu Foundation. This is by no means a small achievement by any standard.

Some Pictures of Dala Foods Brands. All these brands have pioneer status. Dala Foods is an indigenous firm. Source: [14].

Key success factors

The success story of Dala food can be attributed to its ability to practice and maintain its mission and core value: "To produce clean, cheap, and quality products that meet our customers need." This is achieved through developing locally relevant, quality products that are not only affordable but also scalable. The company was also able to create a strong value proposition for its products at the right price points through a combination of product re-engineering, smaller pack sizes, and low-cost operating models.

Another driver of the company's success was its effective brand building strategy. Getting brands into consumers initial consideration set is very important in emerging markets such as Africa than elsewhere. With this knowledge, Dala Food vigorously built its city tea, instant *Kunun tsamiya*, *Biski* and *Fura* to acquire an indelible position in the consumers mind through aggressive promotion and marketing strategies. Similarly, the company has painstakingly developed and maintains a set of activities to effectively get its product to market such as account management, order taking, delivery, payment and in-store merchandizing. Using his vast experience as an erudite merchant, the late chairman of the company Alhaji Safiyanu Madugu took some strategic steps to build a powerful and profitable route to the market, a feat that is being religiously implemented by his heirs today. This strategy apparently works due to a well-developed program based on succession plan, which is reviewed from time to time with cognizance of the original plan in mind. The route to market (RTM) model combines the benefits of direct customer relationships with the cost advantage of outsourcing to achieve distribution economies.

Other steps cover effective management of the distribution network within Kano and outside the state as well as developing a compelling retail value proposition to achieve a win-win solution that drive increased volume, improved efficiency, and outlet loyalty. The distribution network for convenience products like food and beverages in Northern Nigeria is intensive, that is from the company to the distributor, retailer, on to the final consumer. This is done with a view to make the products readily available and accessible to the target market. However, this channel may likely change in the near future, when the company starts exporting its products to the neighboring West African countries like Niger, Cameroon, Chad, Togo, and Ghana. To achieve this, Dala Foods intends to use indirect export, first, through domestic-based export merchants and reliable export management companies. As the operation grows further, we will do it directly by establishing a home-based export unit to market the products, or export sales representative to sell the products in foreign country or by appointing a reputable but reliable distributor based in the host country.

Furthermore, the company has absolute control of the production process. It is pertinent to note here that the production process of *Kunu*, *Fura*, and *Biski* was pioneered by the company as it was the only entity that started to produce these products using such technology, so there is absolute control which gives it advantage over others and makes it difficult for others to enter the market without the permission of the company, thus creating a strong entry barrier. Another critical success factor is the availability of raw material because all the materials are wholly sourced locally. The main raw materials include fresh tea leaves, millet, ginger, cloves, and pepper; all in natural form with no additives or artificial preservatives. This provides the company with competitive advantage of making product easily available, qualitative, and affordable.

In a nutshell, Dala Foods Nigeria owes its success to its key role in supporting the local agricultural produce through its proactive product development, limited line product management strategy, and strategic market niche operations" [15].

Source: Adopted from [15].

5. Conclusion

From the foregoing discussion, it is hoped that the chapter has provided a clear basis for proper understanding of product development and management toward improved and sustainable company performance. It is important to note that the tasks and strategies discussed in this chapter cannot be carried out by the product/brand manager or any other body charged with the responsibility for product management alone, but in conjunction with other units in the organizations. This is because a product manager has to relate with such units like research and development, engineering, production, marketing, finance, advertising, procurement, etc., in order to be successful. Thus, a brand manager is expected to be a good diplomat and a team player in order to succeed.

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Author details

Musa Gambo Kasuwar Kuka

Address all correspondence to: gambokk@gmail.com

Department of Marketing, School of Management Studies, Kano State Polytechnic, Kano, Nigeria

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Chapter 3

Product Design Process and Methods

Jinxia Cheng

Additional information is available at the end of the chapter

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Abstract

Suitable design procedures and methods will lead to twice the result with half the work. Hence, good products need a good beginning in the design process. The design procedure is the basis for guiding the steps of design process, while the design method is the guarantee for effectively developing the design process and improving its quality. A clear and reasonable process can lead to a simple and smooth way in design, while the proper use of creating techniques can let the designer find a better way to solve the problems in a wider range, so as to develop and design a good product.

Keywords: product design, design method, creating technology, design process, survey, evaluation

1. Introduction

"What is a process?" A process may be defined as "a series of steps, actions, or operations used in making something or bringing about a desired result: a manufacturing process" [1]. Similarly, a design process can be defined as a sequence of creative problem finding, analyzing, and solving steps used by the designer to develop an appropriate design solution for the given client, which is an organizational framework used by designers during the process of product design.

Design activities are complicated and interlocking. There must be clear steps to plan and integrate, and the whole process should be rationally arranged according to scientific laws, so as to achieve the final design goals clearly, as shown in **Figure 1**.

In these steps, series of problems, puzzles, and brand-new ideas will be brought in, to analyze to lead our future products. We need to find the key point to explore our product, know about

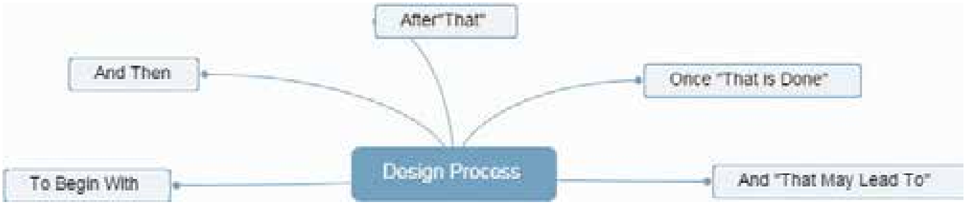

Figure 1. Design process.

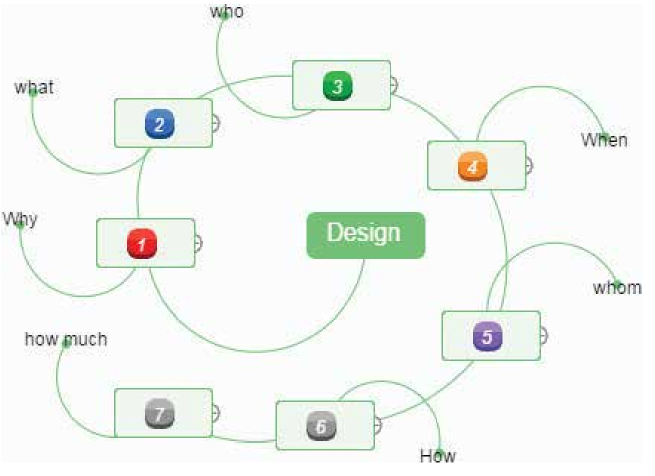

Figure 2. Design analyses.

the market and potential customers, and get important information about the variety of functions, what is more, we need to deal with the whole developing and design operations and have control on its correspond costs, as shown in **Figure 2**.

2. Definitions and relationship between product design process and methods

2.1. About product design process

The product described in this chapter refers to the concept in a broad sense, which refers to the sum of the products formed with a certain purpose and to meet the needs of targeted people as well as nonphysical services. Its general process is shown in **Figure 3**.

Modern product design is a planned, step-by-step, targeted, and directional creative activity. The design process refers to the development process of the design and the order in which the design tasks are completed. According to the arrangement of the process, it can be divided into linear programs, parallel programs, and complex programs. It is an organic combination of finding, analyzing, and solving problems.

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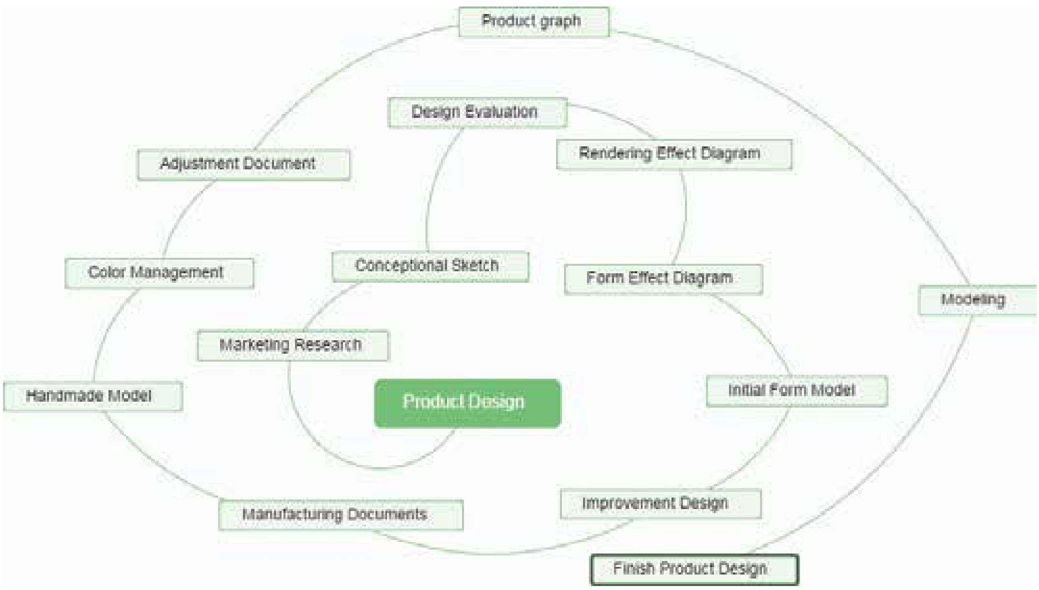

Figure 3. General product design process.

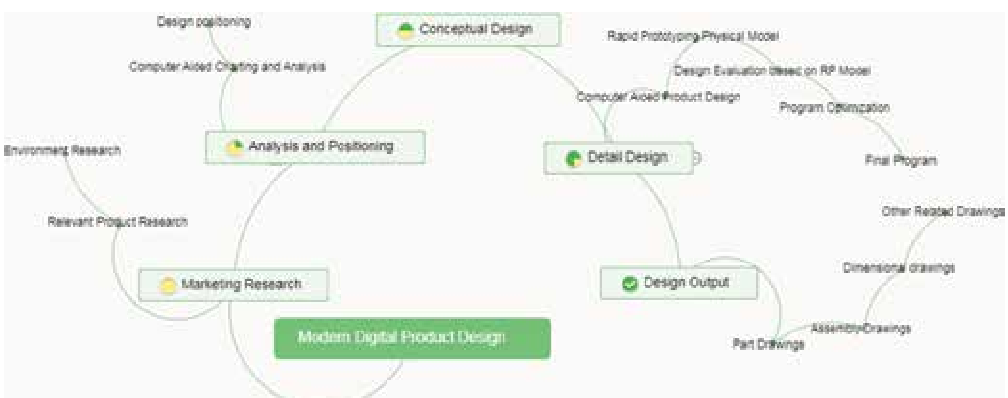

Figure 4. Modern digital product design process.

With the advancement of technology, computer-aided design and manufacturing have been widely used in the product design process. For example, in the market research stage, computer data analysis can be introduced; in the concept stage, product sketches, renderings, and even real physical models are created through rapid prototyping based on computer-aided design, as well as design evaluation, reversing, and optimization iterations. Thus, the design process of the above figure can be reduced to the following modern digital design process as shown in **Figure 4**.

2.2. About the design methods

Methods refer to the sum of the receipts that can be used to achieve certain purposes in any fields. When people want to know and transform the world, they must engage in a series of

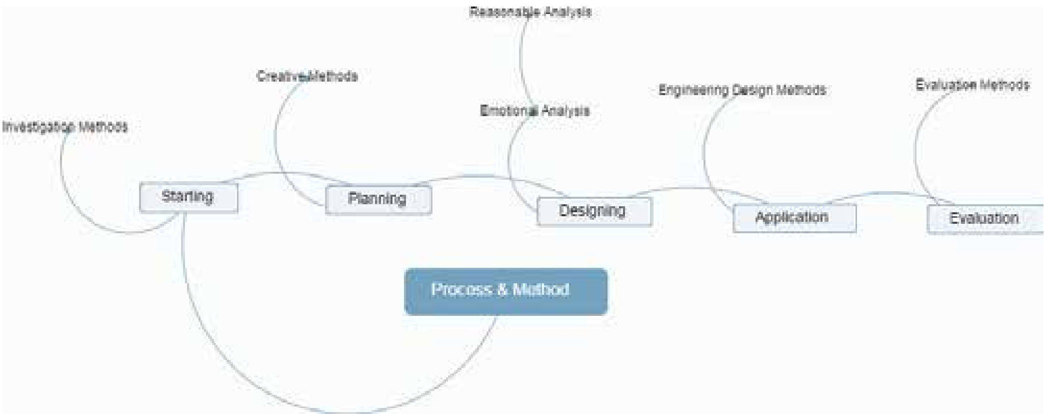

Figure 5. Relation between process and methods.

thinking and practical activities. Those various methods used in the activities are collectively referred to as methods. No matter what you do, you must have proper methods, and the correctness or inferiority of the methods directly affects the success or failure of the work.

The main features of modern design are optimization, dynamics, diversification, and computerization. Commonly used design methods mainly include catastrophe method, information theory method, system theory method, discrete theory method, intelligent theory method, cybernetic method, correspondence theory method, optimization method, fuzzy theory method, and art theory methods [2].

2.3. Relationship between process and methods

As for the relationship of product design process and methods, they complement and rely on each other, which is shown in **Figure 5**.

Firstly, the design process determines the steps of the design, while the method determines the design measures and effects.

Secondly, the design process itself requires specific methods and overall strategies to guide and support, and methods must be adapted and changed according to specific procedures. A clear and complete design process can guide in an orderly manner, simplify, and optimize the results in process. While designing, the appropriate method involved can solve the design problem efficiently and creatively.

Finally, a design program provides a platform for the application of the method, which ensures the smoothness and efficiency of the program.

3. Product design process

Generally speaking, product design involves four periods, namely, the research phase, the analysis and positioning phase, conceptual design phase, detailed design phase, and the design output phase. According to different design objects, the specific matters of each stage are slightly different and complicated.

3.1. The research phase

Design and research are in the initial stage of the design process. Knowing what we have, what we want, and where to get as well as how to get required information from seeing the micro-knowledge to know the significance, using existing information as the starting point, by means of analysis and synthesis methods, etc., to integrate the important influencing factors of the products involved, so as to guide the follow-up design in a targeted manner.

Generally speaking, the research phase mainly focuses on people, machines, and environment, as shown in **Figure 6**. Among them, people include target users, potential users, producers, sellers, recyclers, etc., which are related to the product life cycle; gender, age, education background, income level, social status, family conditions, as well as other factors which reflects in status, lifestyle, and values all have a profound impact on the future direction of product design. The machine mainly refers to the various attributes involved in the design object and related products including the current status of the market products and various property expectations of the products involved such as function, form, structure, color, human-machine relationship, usage, carrying method, etc. The existing attributes of the product market have a certain reference and guiding role for future design. From the existing market survey, we can understand the distribution and gathering of market products, so as to find the opportunity of post-development positioning. At the same time, the investigation of the attributes of future products can further clarify the product characteristics, zero to thin, and gradually deepen the refinement of product concept until the entire product design process is completed. The environment mainly refers to the natural and human context in which

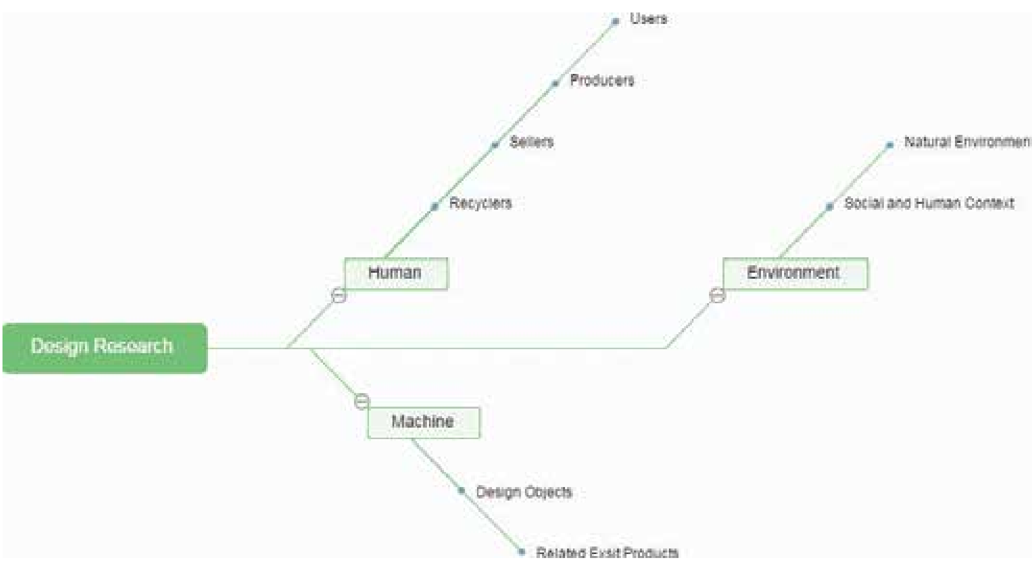

Figure 6. Design research.

the design object is located. Any product is used in a certain time and space and social environment, and the product status should match the current environment, which can highlight the design intent and the characteristics of the times.

3.2. The analysis and positioning stage

The analysis and positioning stage is mainly based on the abovementioned research information. Through the actual deep investigation of people, machines, and environment, we are firstly able to analyze the direct and potential needs of the users, so as to achieve design customization in a targeted manner. Secondly, the investigation of the machine can be intuitive and effective in discovering market development opportunities. In general, we can explore products from two aspects. On the one hand, in the state of market agglomeration, it means that the product status is very suitable for the current trend and can meet the needs of most users. It can be used as a follow-up product development, taking the advantages of popular goods and targeting the mainstream of the market. On the other hand, as to the market's unpopular performance, the challenge of the alternative way of solving problems with the mutant thinking and the use of unique strategies to creatively complete the development of brand-new products can be reversely considered, as shown in **Figure 7**. In terms of environment, in view of the indivisibility of product use and environment, the product environment is reversely inferred from the use environment, and the consideration and development of the support are beneficial to maintain the performance of the product for a long time, thereby ensuring the service life of the product and saving the human, material, and financial investment in the industrial chain.

On the basis of design analysis, the related aspects of the products involved are positioned to create a benchmark for subsequent series development and visual design, which lays the design direction and basis for the whole design process.

3.3. Conceptual design stage

Conceptual design is a series of organized and targeted concepts of concise design based on analysis of the previous market demand and user needs. It manifests itself as an evolving

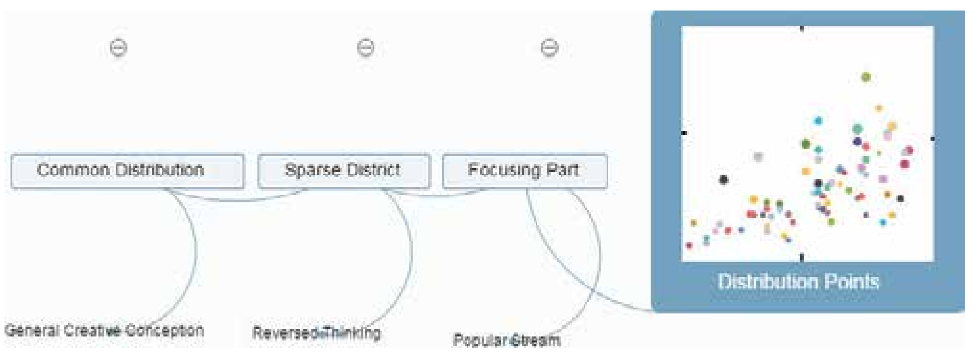

Figure 7. Distribution analysis.

process from coarse to fine, from fuzzy to clear, and from abstract to concrete, which is a preparation stage for the visualization of the design conceptions after the above design positioning is determined.

Conceptual design determines the main purpose and developing direction of the future product, through which we can save our resource input as much as possible, help the following production and sales, extend the profit margin, and effectively estimate and guide the late recycling issues. Thus, conceptual design in the initial stage of product is undoubtedly a crucial part of product life cycle.

3.4. Detailed design

Detailed design is a visualization process based on the previous design concepts. It is extending and diverging based on design concepts and gradually forms a visual clear plan, as

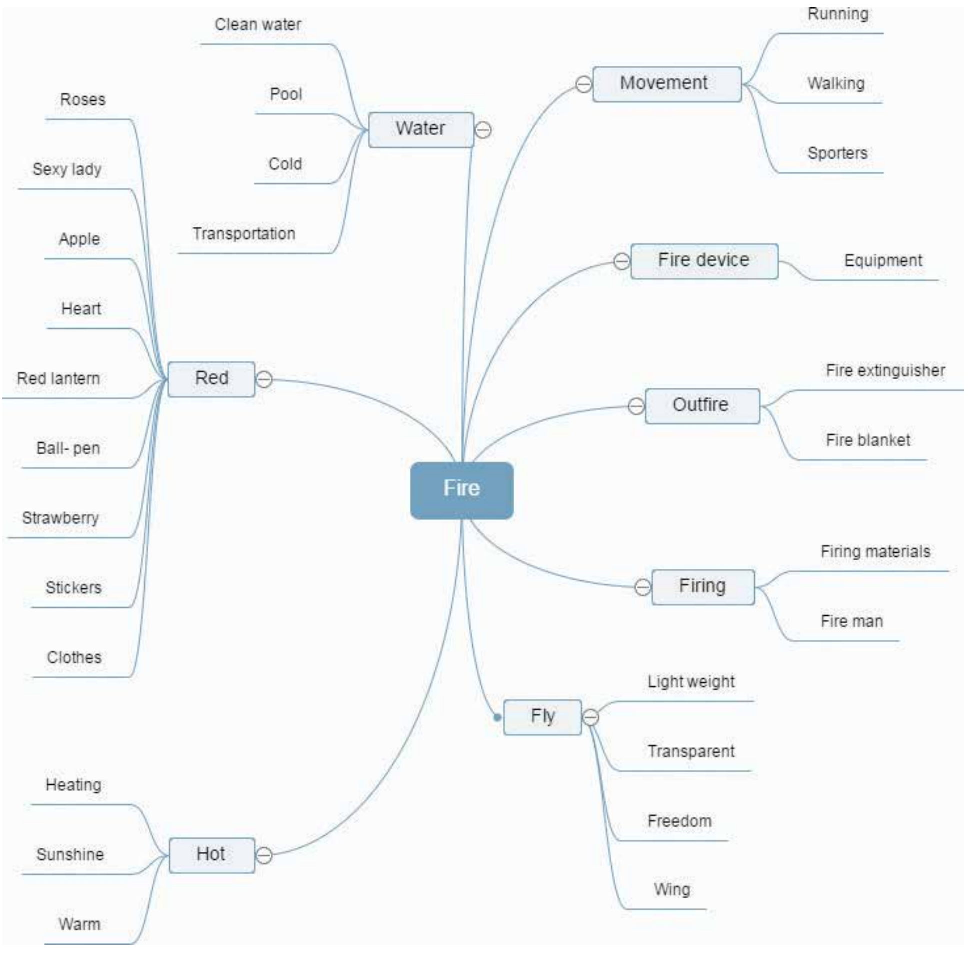

Figure 8. Divergent thinking.

shown in **Figure 8**. Based on this, the process of design evaluation, program selection, and optimization, as well as the product expressions, is carried out. With a same script, different interpretations produce different works. The same is true of the design concept. Focusing on the abstract design concept, divergent thinking, and extension, starting from different angles,

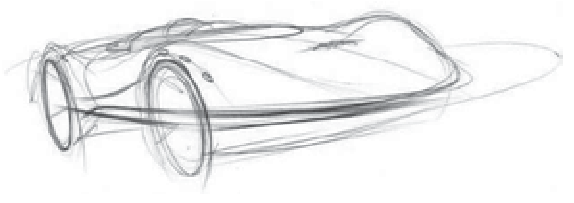

Figure 9. Original handmade sketch [3].

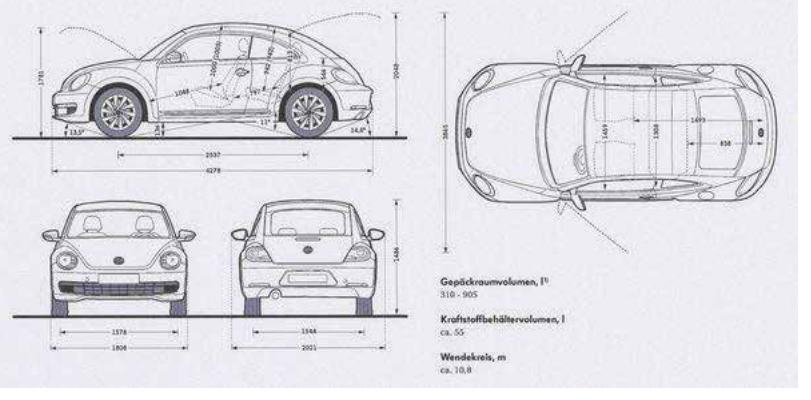

Figure 10. Computer-aided sketch [4].

Figure 11. Handmade model [5].

different characteristics, different ways, etc., the abstract concept is gradually associated with concrete objects, and the design process is gradually cleared and definitely expressed, as shown in **Figures 9** and **10**.

In terms of design evaluation, program selection, and optimization, based on the advancement and popularization of modern technology, computer-aided design and manufacturing technology can be fully utilized; digital models can be built with design sketches, and even 3D physical models can be obtained by using rapid prototyping technology, as shown in **Figures 11–13**. The model carries out product functional design, structural design, color design, human-machine interface design, etc. At the same time, according to the evaluation results, the digital model or physical model is optimized and improved through computer-aided design software and reverse engineering technology, as shown in **Figure 14**.

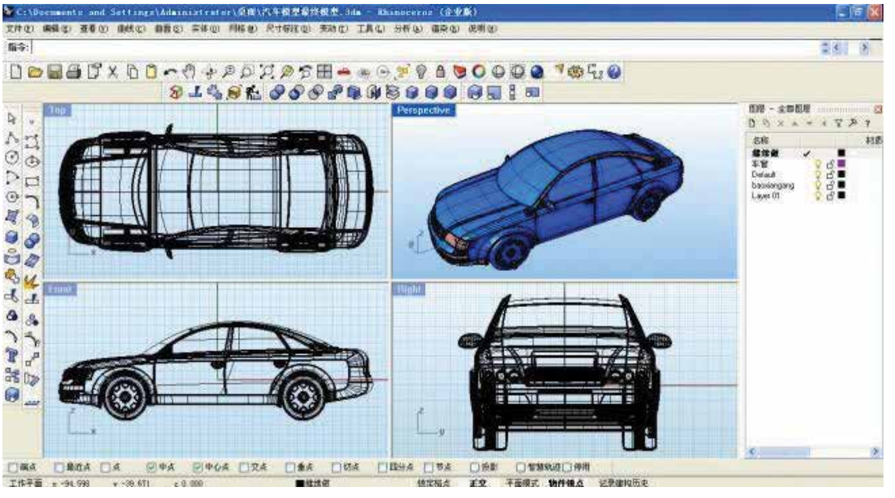

Figure 12. Computer-aided model [6].

Figure 13. Prototyping model [7].

Figure 14. Reverse scan [8].

3.5. The design output stage

The design output stage mainly refers to the expression of design results and the preliminary preparation for the following production. At this stage, through the design renderings, dimensional drawings, parts drawings, construction drawings, detail display drawings, structural drawings, etc., the design results are presented in a detailed and complete manner. Through this way, the above design work is closed and integrated on one the hand. On the other hand, these outputs also provide the basis for production and construction after the design phase.

4. Product design methods

In different design stages and target objects, the complexity of the steps is slightly different and so as the design methods involved. Generally spoken, blows are the common methods involved in the main four steps of product design.

4.1. Design survey

With the advent of the information age, the world has become smaller and smaller, and the acquisition of various information has become feasible and convenient. The factors that people choose products are increasingly influenced by the individual and the mainstream. At the same time, in the whole product design process, each step has a series of internal or external constraints. The design is just like “dancing with shackles.” Every involved part needs information intervention and guidance and gradually coordinates, optimizes, and iterates so as to initiate better ideas and works. This factor makes the investigation and research at the beginning of the design particularly important.

Common survey methods include comprehensive surveys, typical surveys, and sample surveys. The main difference is the coverage of survey samples. When carrying out the survey,

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firstly, it is necessary to prepare for the whole investigation, determine its objectives, and clarify whether its form is inquiry, observation, experiment, or case, and based on preliminary analysis, formulate the basic ideas and problems of the investigation, and highlight the key points concisely as much as possible.

The second one is to conduct an investigation. This stage is the way to obtain information. Incorporate the survey objectives to determine the respondents, select appropriate survey techniques to determine the query items and design questionnaires, and then conduct a field survey in an orderly manner.

Finally, collate the survey results by analyses and research, draw into various forms, and then present analysis results of the survey, as shown in **Figure 15**.

At different stages of design, surveys are conducted around different surveyees, with different design goals and processes to make sure the final results are armed with comprehensive information feedback, so as to develop and create new products in a targeted manner.

4.2. Creating techniques

The creating technique is an important part to improve the design quality. It is a means to use the multi-directionality, the differentiation, the suddenness, the broadness, and the flexibility of creative thinking to propose new ideas. According to different classification criteria, creating techniques can be divided into different types. Such as according to the personality characteristics of the creative team members, the creating techniques can be divided into open speech and anonymous expression. The typical representative techniques are brainstorming

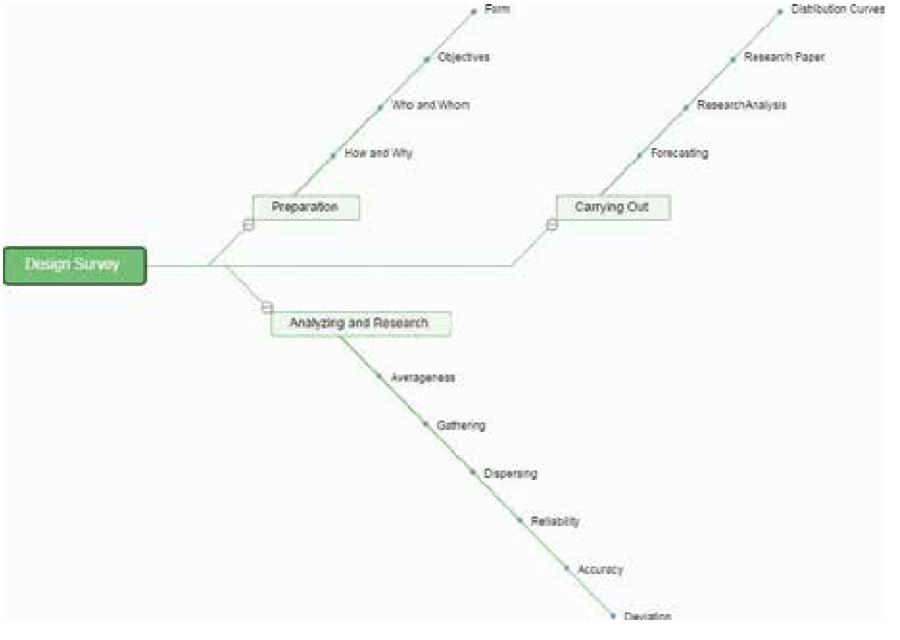

Figure 15. Design survey.

and 635 method. The former is free expression of team members, not bound to each other, and open to freedom. By this free style, the creativities of the group are stimulating, while the latter is to be silence in the whole previous period. Each one needs to avoid mutual interference and privately express their ideas in a recorded way. According to the nature of the creative proposal, it can be divided into active stimulating and passive stimulating. The typical representatives are the comprehensive method and enumeration method. The former uses abstract expressions to let the team members of different professional backgrounds associate with each other freely; the latter is based on existing objects, enumerate expressions and deep cognition one by one, and then use these expressions as sources of creativity. Flexible selection of different creative techniques at different stages of design is needed. As shown in **Figure 16**, it is a passive method by which we can make ourselves much more aware about the design purpose and processes after the relevant technique.

4.3. Product form design method

This stage of creating techniques is designed to complete the visualization process from design concept to product modeling. After completing the functional positioning of the product, the product structure and the later modeling design become the final platform for design creativity. Therefore, the product design method mainly includes the following three steps.

Firstly, decompose the product into individual parts according to the previous function and form positioning. Secondly, confirm the changeable parts of each shape. Thirdly, the changeable part is changed. Finally, recompose the relevant individual parts into a complete one, and select the best shape you evaluated. For example, a simple face will be a brand-new one

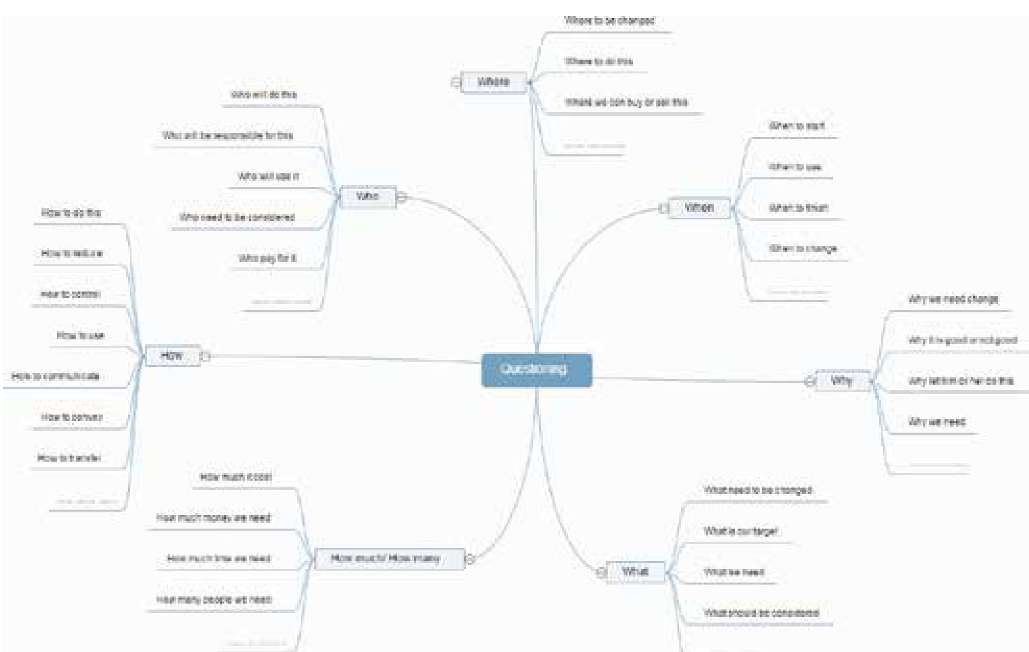

Figure 16. Questioning.

if we change parts of it, including face skin color and facial features and any other aspects. In principle, the number of new schemes is the same exponential power of the changeable part. As shown in **Figure 17**, the principle sum of the complete scheme is n^n.

4.4. Design evaluation method

Design evaluation is to compare and evaluate the solution to the problem in the design process, thereby determining the value of each program and judging its merits and demerits in order to screen out the best design. The meaning of "program" here is extensive and can be in various forms, such as principle program, structural program, modeling program, etc. From the perspective of its carrier, it can be a component or an overall drawing, or it can be a model, a prototype, a product, etc. In general, the "program" referred to in the evaluation is essentially the answer to the problems encountered in the design. The significance of design evaluation is to consciously control the design process, to target the direction of the design, and to assess the design plan with scientific analysis rather than subjective feeling, which provides designers with the basis for judging design ideas. Through design evaluation, the quality of design can be effectively guaranteed, and the best solution in which all aspects of performance meet the target requirements can be selected among many design programs. Secondly, proper design evaluation can reduce the blindness in the design and improve the efficiency of it. In addition, the applicative performance of evaluation can effectively verify the design plan, find out deficiencies during the process, and provide the basis for deeper design improvement.

In the actual evaluation process, due to the complexity of the design factors, the main influencing factors are generally selected. According to different design objects and different stages of the design, different evaluation objectives are determined, and the most appropriate content is selected to establish the evaluation target system. After selecting the evaluation items, the

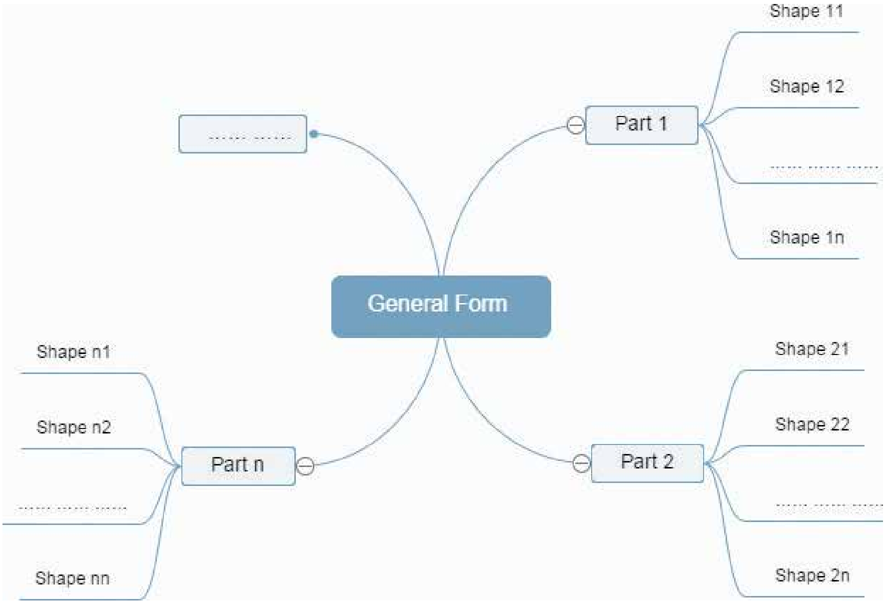

Figure 17. Questioning method in general form design.

Figure 18. Design evaluation.

weighing coefficients are, respectively, set according to the importance of each evaluation item, and the entire project evaluation process is finally completed as shown in **Figure 18**.

5. Conclusion

The design procedure is the basis for guiding the steps of design process, and the design method is the guarantee for effectively developing the design process and improving its quality. A clear and reasonable process can lead to a simple and smooth way in the design, while the proper use of creating techniques can let the designer find a better way to solve the problems in a wider range, so as to develop and design a good product.

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Author details

Jinxia Cheng

Address all correspondence to: 414708353@qq.com

School of Software Engineering, Jiangxi University of Science and Technology, Nanchang, China

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Chapter 4

Configuration of a Customized Product

Izabela Kutschenreiter-Praszkiewicz

Additional information is available at the end of the chapter

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Abstract

The chapter discusses problems of the product configuration process and application of chosen methods to represent the knowledge related to this process. One of the most important issues in product life-cycle management is to identify customer needs and combine them with product's technical and trade characteristics. The main tasks related to product configuration are focused on identifying the most suitable product to a particular customer, product decomposition, and estimating product characteristics. In the presented approach, identification of customer needs was discussed, and a product decomposition method was presented. The quality function deployment (QFD) method was suggested to be applied as a product and production process data integration tool, where engineering characteristics of a product are combined with its trade characteristics.

Keywords: QFD, product structure, product customization, product decomposition, knowledge base

1. Introduction: product customization

In recent years, in order to enhance ability of an enterprise to quickly respond to dynamic changes in the market, the concept of product customization has been introduced into industry [1, 2]. Customer requirements cause increased product complexity and shortened product life cycle [3–5]. In made-to-order (MTO) manufacturing enterprises (ME), product architecture is usually modularized, and components are standardized. Product configuration is focused on selecting product modules or components and assembling them according to customer requirements [6]. Reusing certain modules can simplify a new product design and improves ability of an organization to offer greater product variety to the market [2, 7, 8]. The customization level is usually defined during the product design phase, in order to specify which components, parts or modules, known also as a configuration item, can be customized and selected according to customers' expectations [9, 10]. The concept of open-architecture product (OAP) can balance product economy and user requirements and can be applied to functional modules and adaptable interfaces for users to replace or add personalized modules into an original product in order to meet a personalized need [11, 12]. Any customized product is designed based on customer's requirements [13] and has to meet diversified requirements of product users. Product structures and design methods, such as a product configured from modules, are required to meet the need in developing personalized products with a cost-effective solution [12, 14, 15]. Product variant management has the goal to offer as many product variants as possible to the customer but keep the internal variety as low as possible at the same time [16]. Product design requirements should include the characteristics of modularity and reliability, as well as the cycle time and the implementation of production process reconfiguration [15, 17]. The three main goals of each manufacturing systems are cost, product quality, and responsiveness to markets [18].

Reconfigurable manufacturing system (RMS) is a recently proposed, new class of manufacturing systems [19]. RMS has the ability to update itself, in order to answer dynamic requirements or unpredictable failures [20], and is characterized, among others, by modularity: all major components are modular, and modules are designed with interfaces for component integration [21].

2. Quality function deployment

Quality function deployment (QFD) is one of the methods useful in product customization, taking into consideration customer requirements and product and production process characteristics. QFD is developed as a "method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process" [22]. Quality function deployment (QFD) was developed as a product-oriented quality technique, which formulates customer expectations and then translates them into measurable product and manufacturing characteristics (**Figure 1**). For this purpose, a basic QFD matrix is extended to a series of matrices (**Figure 2**) [23, 24].

QFD provides:

- Product development, which takes into consideration customer requirements
- Integrating thinking in all stages of product development
- Identification of inconsistency between requirements analyzed from different points of view

The development of new products requires performing an analysis of alternative products and recognizing the desired product attributes. The QFD matrix determines the relations between customer needs (denoted as "what's") and product characteristics (denoted as "how's"). QFD joins customer requirements and product characteristics in a matrix, with a list of customer requirements on the left. The first column is related to the first row of the matrix

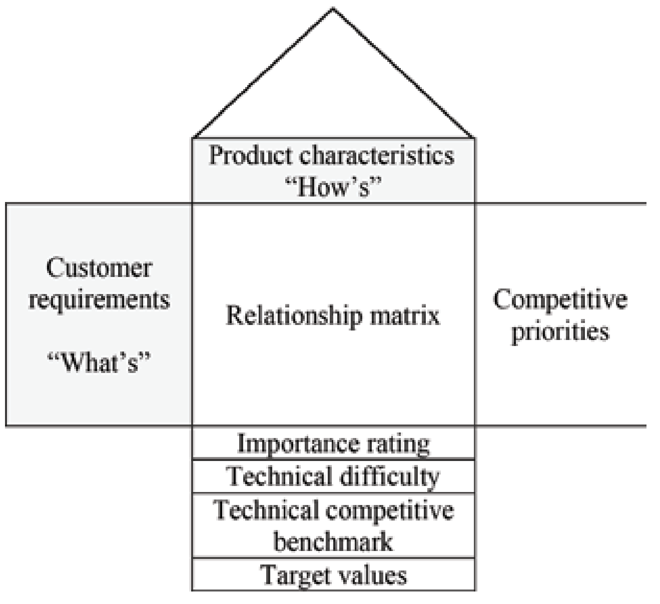

Figure 1. QFD matrix structure.

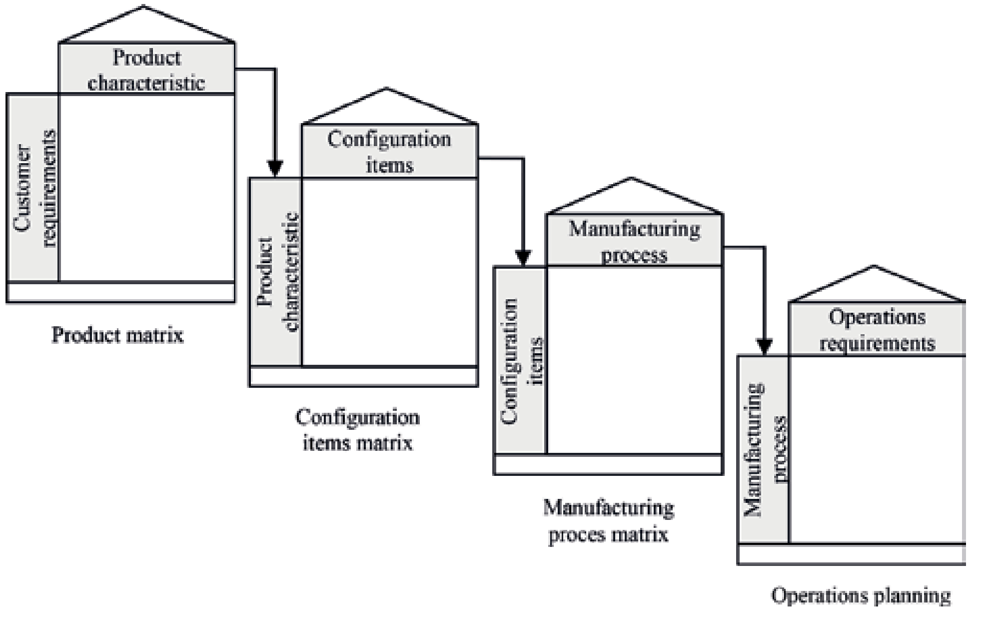

Figure 2. QFD sequence of matrices.

which specifies engineering characteristics of the product. The top part of the matrix, called a "roof," indicates how product characteristics interact. The right part of the matrix includes an assessment of the products. The target level of each product characteristic is presented at the bottom of the matrix.

QFD consists of a series of matrices, in which the first row of one matrix becomes the first column of another one [25–27]. The matrices sequence (**Figure 2**) regarding product characteristic, configuration items, manufacturing planning and operation planning matrix.

The main steps in QFD include [28]:

- Identification and prioritization of customer requirements. Several information sources can be used for this purpose, such as [29] potential customers, the firm for which the product is being made, similar products and any authorities that can impose restrictions on the product (standards, safety, etc.) The customers' requirements are prioritized based on its relative importance, using a 1–5 rating scale, with 1 having the minimum priority and 5 having the maximum priority. The requirements are placed on the left side on the QFD matrix. Analyzing customer requirements needs a certain product function and a certain definition of dimension parameters [30].
- Technical requirements related to a product should be specified, and product features should be identified. Each product has its own attributes, and these attributes should be described [30] in the first row of a QFD matrix.
- A relationship matrix between "what's" and "how's" should be established. Relations between customer expectations and product characteristics constitute the core part of the matrix. Typical relations between "what's" and "how's" are no relation, weak, strong and very strong [23]. Symbols or numbers can be used as correlation marks.
- A trade-off matrix should be established, which is often named a roof matrix and shows the relationship between various technical requirements. A trade-off is positive when an increase of a feature value causes an increase of another one, and a trade-off is negative when an increase of a feature value causes a decrease of another one.
- Customer competitive assessment is focused on comparing competitive products and product being developed, taking into consideration customer requirements. The right part of the matrix should include an importance coefficient of customer requirements. Customer expectations are rated, and product features importance for the customer is established. The next task in this step is product competitive comparison, which should be made with the use of a scale from 1 to 5, where 1 means the least satisfying and 5 stands for excellent performance [29].
- The next step is technical competitive assessment of products. Each product feature pointed in the first row of the QFD matrix should be rated taking into consideration product comparison situated in the bottom part of the QFD matrix. Product technical feature analysis includes assessment of the degree of technical difficulty which represents the capability of an organization to make a given feature of the product. Technical competitive benchmark is a study that compares specification of different products, so, in this stage product alternatives are characterized and compared. Finally, target values of product parameters are set in the bottom part of the matrix.

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3. Customized product configuration with a QFD-based knowledge base

3.1. Knowledge representation

Product adaptation needs knowledge in the field of product and production process redesign. Product adaptations consist in changing technical documentation of products from the enterprise product portfolio. To support the redesign of product configuration, it is necessary to know the answers to the following questions [31]:

- What are the main product features noticed by the customer?
- What are the main product features noticed by the producer? Is it necessary to select the most important product engineering and trade characteristics and specify target product characteristics?
- What is the product structure?
- What kinds of changes are necessary to introduce to the product?
- What product or product part from the product portfolio is close to customer requirements?
- Which product parts have to be redesigned?
- What is the risk regarding product failure?
- What product engineering and trade characteristics can be offered to the client?

QFD-based knowledge base (QFD-KB) for product configuration needs proper methods of knowledge representation. There is plenty of research work focused on gap analysis between knowledge area, knowledge type, and methods of data analysis [32, 33].

Knowledge comes from different sources and could have a different form. Knowledge could be tacit, which means preverbal—understood as unvoiced—unspoken, intuitive and emotional. On the other hand, explicit knowledge is expressed clearly, verbally or in mathematical models [34].

Knowledge should be codified and stored in a way that enables other people to understand and reuse it easily [34].

Formal description of knowledge is called knowledge representation. According to the level of formalism used for knowledge representation, we can distinguish procedural knowledge, which defines algorithms that help to achieve given goals, and declarative knowledge, which gives the solution without analyzing the problem structure.

There are different methods and tools which could be used for knowledge representation. Knowledge representation methods include, among others [34]:

- Decision rules—which contain expressions such as IF $x1$ is $F1$ **and/or** $x2$ is $F2$ **and/or** … xn is Fn, THEN y is P where $x1, x2, ….. xn, y$ denotes objects or attributes and $F1, F2, …….$ Fn, P denote values. Decision rules describe both information elements (expressions) and relations between them, and therefore, a set of such rules (r) defines a knowledge base: $KB = \{r1, r2,…\}$.
- Decision trees—which are graph representations of the decision process. The inspection of the condition in the decision path starts from the beginning node called the root and ends in the leaves which give the decision.
- Frames are used when information units are characterized by many important features. The structure of a simple frame contains three different lines: a heading with the frame name, a pointer to another frame with appropriate relation, and slots defining attribute names and values.
- Semantic networks capture knowledge as a graph, in which nodes represent pieces of information (objects, concepts, or situations in the problem domain), and the arcs represent relations or associations between them.
- Artificial neural networks (ANNs) are inspired by neurons in the brain and have become a popular knowledge representation useful for learning [35]. Among many kinds of ANNs, feed-forward ones are widely used by researchers who apply them as a tool for data classification or as a predicator. The idea of ANN usage is to create a learning set, which includes data characterized by input and output features. During training, ANNs create a model which is able to transform input features into output features of a data set. If the predicted or classified data depends on many variables (features), ANNs are a convenient tool for analyses.
- Case-based reasoning (CBR), in which the problem-solving method is focused on finding the solution in the base of examples (cases). The case which has been found will be adapted to the new usage. This method is applied when knowledge is presented as a description of cases.

Knowledge can take many forms, and it is necessary to identify the kind of knowledge representation method which is the most suitable for solving a particular problem.

In the presented customized product configuration QFD-KB, the following methods of knowledge representation were used [32]:

- Procedural knowledge used for identifying the product features recognized by the customer and identifying the product features recognized by the producer.
- Declarative knowledge applied to define the evaluation rules.
- Artificial neural network (ANN), used for assessing the missing manufacturing process parameters.
- Case-based reasoning (CBR), applied for identifying product alternatives.

The data and knowledge generated and used during manufacturing may be related to products, machines, processes, materials, inventories, maintenance, planning and control, assembly, logistics, performances, etc. [33].

3.2. Algorithm of QFD-based knowledge base for product configuration

Enterprises develop data bases to store different types of data, e.g., data orders, codes of products, technical documentation related to products and the manufacturing processes, and product and process failure data.

Taking into consideration categories mentioned above, product configuration needs information related to customer requirements, product use circumstances, needed product characteristic analyzed from the functional point of view, product portfolio, parts characteristics, and manufacturing process characteristics.

The problem of determining product configuration can be structured according to the decision method presented in **Figure 3**. The presented approach developing web-based selection system was described by Gibson et al. [36].

Product configuration is divided into three levels including product-level configuration, component-level configuration, and manufacturing parameter-level configuration [37]. These three levels can be developed with the use of QFD series of matrices.

In the algorithm of QFD-KB for product configuration presented in **Figure 4** [32], the methods of knowledge representation such as rules from an expert, case-based reasoning and neural networks were applied.

Product offer preparation requires information regarding product portfolio offered by the enterprise and an evaluation of differences between customer requirements and the offered

Given: a set of products (configuration items) and processes.
Identify: a set of evaluation attributes, create scales, determine the importance and estimate missing product parameters.
Rate: Each alternative relative to each attribute.
Rank: Products (configuration items) from the most to the least promising.

Figure 3. A decision model for product configuration.

1. Identification of product characteristic.
2. Specification of target product characteristics, product decomposition, variants identification.
3. Variants evaluation, choosing the product to be redesigned.
4. Range of change identification, assessment of work time related to technical documentation preparation and the manufacturing process of the configured product.
5. Scheduling tasks related to product configuration, confirmation of product configuration.

Figure 4. Algorithm of QFD-KB for product configuration.

products. Customer service department staff should know how the product characteristics needed by the customer are different from the product characteristics offered by the enterprise and what kind of changes it is possible to implement in the product.

Product offer preparation needs a product requirement analysis, which includes analyzing product functions, reliability, safety, environment, packaging, transportation, storage, etc.

The decision problem solved with the use of QFD-KB for product configuration is how to choose and evaluate the right product from the product portfolio and adopt it to particular customer needs. The knowledge needed to solve this problem could origin from, e.g., experienced staff, databases, and documentation.

Possible data sources used in product configuration are presented in **Figure 5**.

3.2.1. Identification of product characteristics

Identification of customer requirements, product characteristics, their correlations and variant comparison were denoted with symbols presented in **Figure 6**, where a QFD scheme uses a square roof instead of a triangular roof matrix, as it is easier to use in a spreadsheet.

Configuration items should be determined according to the given criterion included in, e.g., [38]:

- Influence on functional and physical product characteristics determined by the client
- Innovatory character of product and process structure
- Safety of product usage
- Product reliability
- Logistic aspects

Identification of product characteristics from the customer point of view could be made in three stages.

The first stage regarding the category of requirements is related to product functions, which, in the case of toothed gear configuration, include, among others, torque transmission, weight of material handling and velocity of material handling.

The second stage regarding the category of requirements includes product environment conditions, e.g., environment temperature, dustiness, humidity, etc.

The third stage regarding category of requirements includes product trade characteristics, e.g., price, delivery time, warranty, etc.

3.2.2. Specification of target product characteristics, product decomposition and variant identification

To create a product, it is necessary to identify product features, quality level, packaging, etc. [37]. Accuracy and efficiency of product configuration depend on product structure used in product configuration.

Procedural knowledge helps to indicate the target value of configuration baseline which is needed for variant identification.

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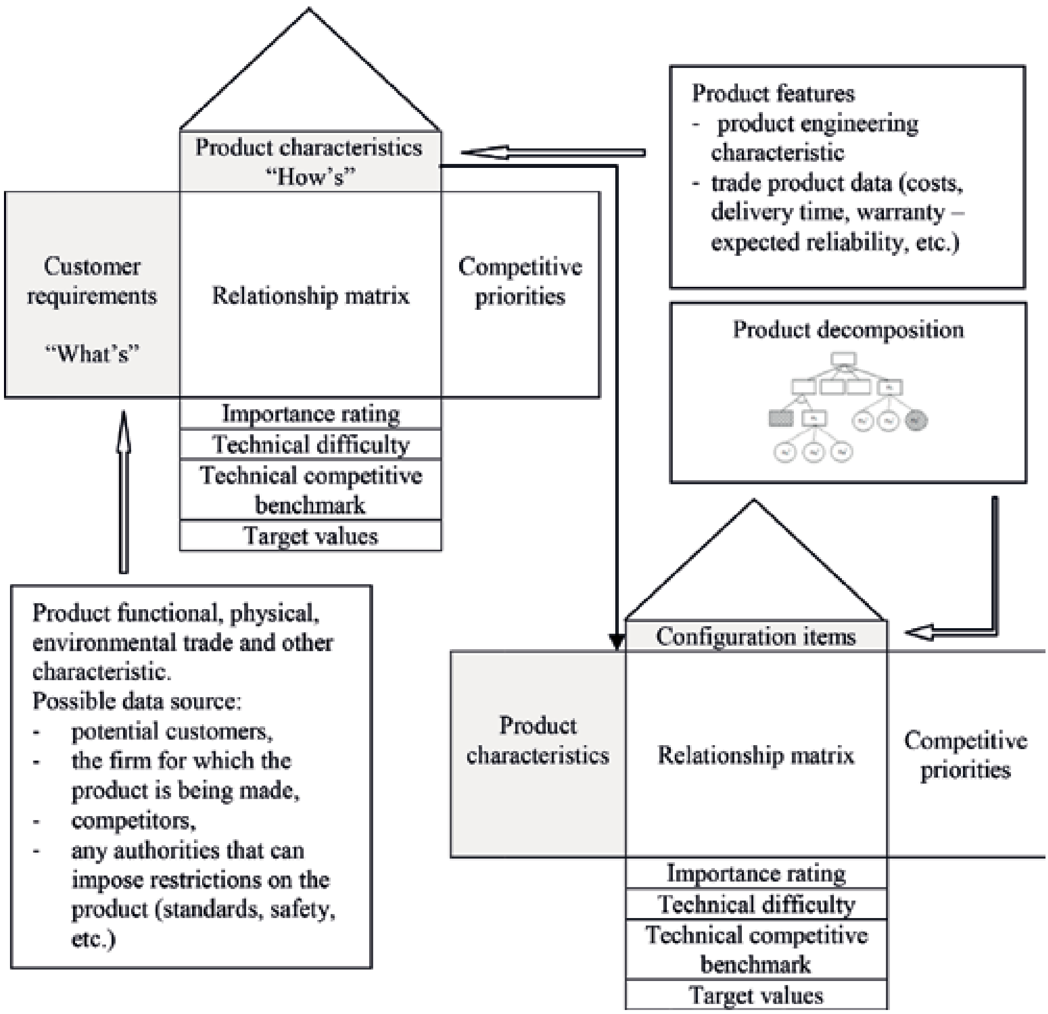

Figure 5. Product configuration data.

In the presented approach, decision rules were used to identify product alternatives. The premises in the proposed rules contain variation intervals of product features, where the conclusions include the proposed products (m_{zl}^{*}).

A general form of the rules is the following:

if $(p_{mk1t}^{wo1} - x_1) \leq p_{mk1} \leq (p_{mk1t}^{wo1} + x_1)$

and $(p_{mk2t}^{wo2} - x_2) \leq p_{mk2} \leq (p_{mk2t}^{wo2} + x_2)$

and ….

and $(p_{mkzt}^{woz} - x_z) \leq p_{mkz} \leq (p_{mkzt}^{woz} + x_z)$

then $m_k = m_{zl}^{*}$

where:

x_z—range of change, z∈Z,

p_{mkzt}^{woz}—target value of product characteristics, z∈Z,

p_{mkz}—product characteristics, z∈Z,

m_k—a configuration item, k∈K,

Z—a set of product characteristics,

K—a set of configuration items.

One of the important issues in product configuration is product decomposition, which provides the combination of components which gives a product suitable for a particular client. Product decomposition and functional requirements will help to answer the following question: which physical element(s) is responsible for the fulfillment of a specific functional requirement?

In literature we can find different approaches to product decomposition [39]. The presented method applies decomposition tree (**Figure 7**) [40], in which "and" nodes means that all components go together into product structure and "or" nodes mean that one of component alternatives should be put into product structure were used.

In product decomposition tree, there were distinguished standard components, and this one needs to be redesigned.

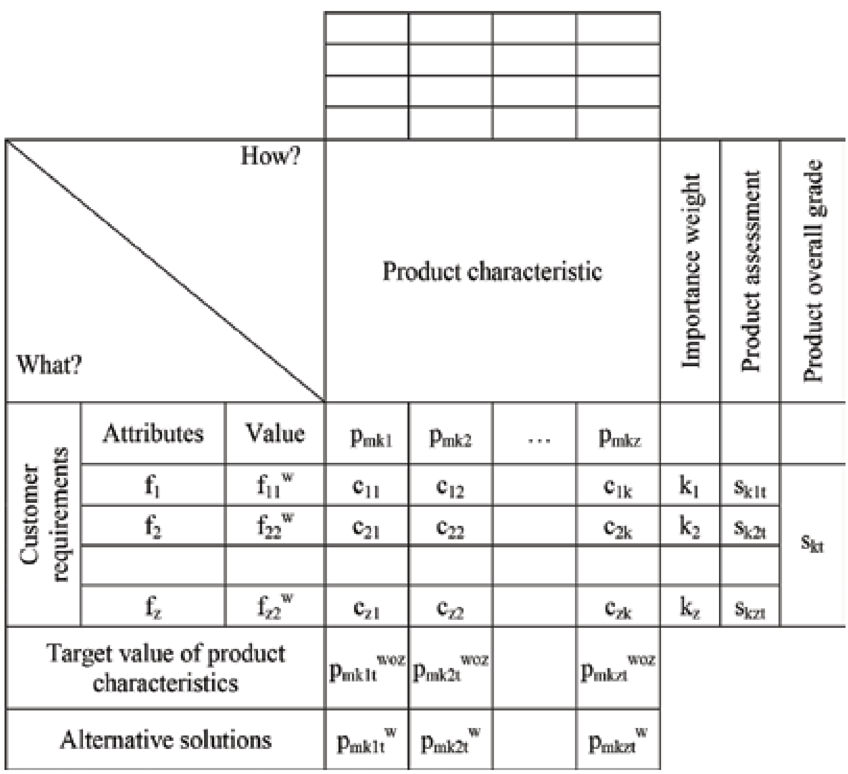

Figure 6. Product planning QFD matrix.

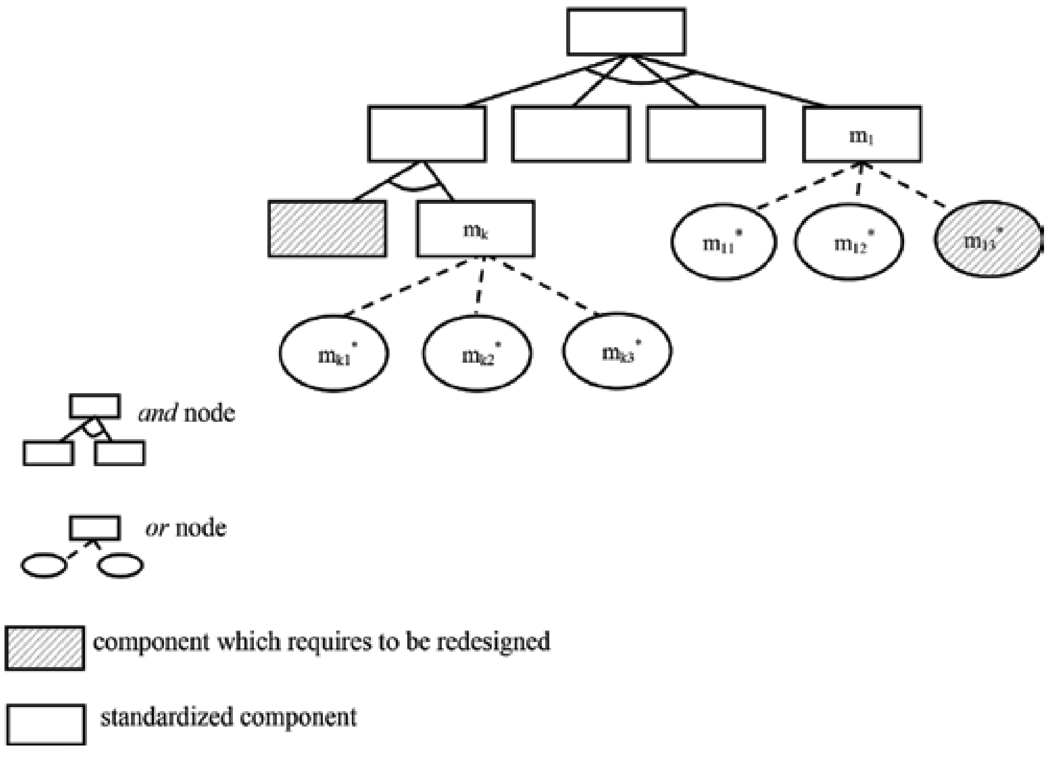

Figure 7. Product decomposition.

The identified configuration items, like product parts, components or modules should be described with the use of attributes and their values as appropriate specification with functional and physical characteristics (**Figure 8**).

Product decomposition in the product configuration process determines how detailed the product structure is. The presented product structures include alternative configuration items, which were characterized in **Table 1**.

3.2.3. Variant evaluation: choosing the product to be redesigned

Comparing product variants identifies the range of product change. The presented rank method applies an evaluation indicator calculated according to the formula (1):

$$w_{kzt} = \frac{\left| p_{mkzt}^{woz} - p_{mkzt}^{w} \right|}{p_{mkzt}^{woz}} \cdot 100 \tag{1}$$

where:

w_{kzt}—assessment indicator for product k, attribute z and variant t;

p_{mkzt}^{woz}—target level of product characteristic;

p_{mkzt}^{w}—offered attribute value.

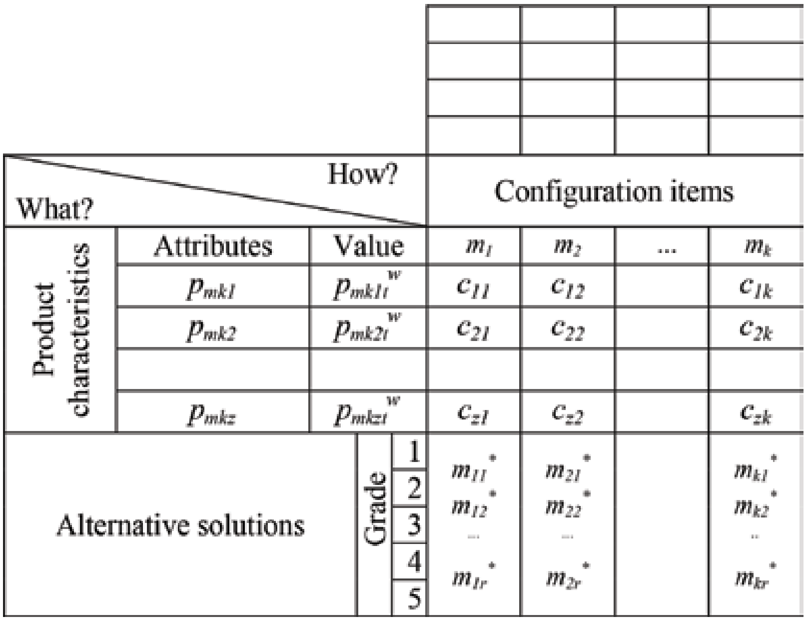

Figure 8. Configuration item planning QFD matrix.

Configuration items	Alternatives	Attributes			
		p_{mk1}	p_{mk2}	….	p_{mkz}
m_1	m_{11}^*	p_{m111}^w	p_{m121}^w	….	p_{mkz1}^w
	m_{12}^*	p_{m112}^w	p_{m122}^w	….	p_{mkz2}^w
	…	…	…	….	…
	m_{1l}^*	p_{m11t}^w	p_{m12t}^w	….	p_{mkzt}^w
m_2	m_{21}^*	p_{m2121}^w	p_{m221}^w	….	p_{mkz1}^w
	m_{22}^*	p_{m212}^w	p_{m222}^w	….	p_{mkz2}^w
	…	…	…	….	…
	m_{2l}^*	p_{m21t}^w	p_{m22t}^w	….	p_{mkzt}^w
….	….	….	….	….	….
m_k	m_{k1}^*	p_{mk11}^w	p_{m221}^w	….	p_{mkz1}^w
	m_{k2}^*	p_{mk12}^w	p_{m222}^w	….	p_{mkz2}^w
	…	…	…	….	…
	m_{kl}^*	p_{mk1t}^w	p_{m22t}^w	….	p_{mkzt}^w

Table 1. Configuration item variants.

Evaluation of product variant could be determined with the use of the rules presented in **Table 2** and the Eq. (2) [45]:

$$s_{kt} = \frac{\sum_z s_{kzt} \cdot k_z}{z} \tag{2}$$

$$s_{kt} \in \{1, 2, 3, 4, 5\}$$

$$k_z \in N$$

where:

s_{kt}—overall grade assessment of fulfilling requirements for variant t and configuration item k.

s_{kzt}—assessment grade of fulfilling requirements for variant t and configuration item k.

k_z—importance weight of attribute *z*.

Product alternative evaluation uses assumptions of the CBR method and decision rules which help to evaluate the presented solutions.

It could happen that the selected product is not suitable for a particular client. In such a case, it is necessary to assess the range of change in the product and the manufacturing process, which helps to determine the trade data related to the configured product.

The presented approach helps to identify the importance of product attribute and compares product components. The assessment of product components helps to choose the proper component variant or the variant which needs to be redesigned.

The presented approach is useful in supporting decisions during product configuration. The results of overall product assessment are given in the bottom part of a QFD matrix (**Figure 8**) [41].

3.2.4. Range of change identification, assessment of work time related to technical documentation preparation and the manufacturing process of the configured product

Changes in a redesigned product are focused on product structure and adapting the manufacturing process to allow to, e.g., fulfill a new function, reduce delivery time and reduce costs.

Assessment indicator		Assessment grade	
if	$w_{kzt} \leq o_{1z}$	then	$s_{kzt}=5$
	$o_{1z} < w_{kzt} \leq o_{2z}$		$s_{kzt}=4$
	$o_{2z} < w_{kzt} \leq o_{3z}$		$s_{kzt}=3$
	$o_{3z} < w_{kzt} < o_{4z}$		$s_{kzt}=2$
	$o_{4z} < w_{kzt}$		$s_{kzt}=1$
Where $o_{1z}, o_{2z}, \ldots, o_{4z}$ – bottom and upper values of parameter w_{kzt}			

Table 2. Assessment rules.

Product customization takes time needed to product redesign and manufacturing. Work time of specified tasks related to product development and manufacturing is one of the most important criteria which contribute to offer attractiveness. Delivery time could be assessed based on work time of product technical documentation and the manufacturing standard preparation.

Work time can be estimated with the use of work measurement methods which determine the length of time to complete a given task.

Work measurement methods include:

- Synthesis and analytical estimation (in this method it is necessary to break down the tasks into elements).
- Analytical estimation (the time required to complete a task is build up from synthetic data).
- Time study (the time of manufacturing tasks is measured).
- A method based on artificial intelligence [42–44]. In case of product redesign, missing data can be estimated with the use of ANN [46, 47].

Work time estimation of the manufacturing process needs the process structure and planning parameters.

3.2.5. Scheduling tasks related to product configuration: confirmation of product configuration

Scheduling the tasks to redesign product is focused on fixing the project deadline. For that purpose methods such as Gantt chart, PERT, CPM and GERT can be used.

Gantt chart is a type of bare chart which illustrates project task order in function of time; duration of each activity is shown.

Another approach presented network-based methods such as PERT, CPM and GERT.

Project evaluation and review technique (PERT) is focused on analyzing tasks involved in the project and enabled fixing the minimum time needed to complete the project. This method uses probabilistic duration of project tasks.

Critical path method (CPM) is a method which calculates the longest path in the project task network, fixing the shortest time to complete the project with the use of deterministic duration of project tasks.

Graphical evaluation and review technique (GERT) use both probabilistic network and probabilistic estimation of project task duration.

3.3. QFD-KB supporting configuration of a motoreducer

An example presents a configuration of a motoreducer used as a feeder device driving gear. Based on the algorithm presented in **Figure 4**, the evaluation of product configuration items was developed.

The first stage of the algorithm was focused on definition of feeder device driving gear characteristic which was placed on the left part of QFD matrix (**Figure 9**).

In the second stage of the algorithm, target motoreducer characteristics were specified and entered to the bottom row in the QFD matrix.

The next stage of product configuration is concerned with identifying the product structure and product decomposition and selecting the configuration items (**Figure 10**). A too detailed product decomposition causes costs, but rough product decomposition causes risk related to product characteristic failure.

Characteristics of configuration item (components, modules, parts) alternatives of feeder device driving gear are presented in **Table 3**.

An example of w_{kzt} coefficient calculation and s_{kzt} grade determination for configuration items of feeder device driving gear was presented in **Tables 4** and **5**. Assessment of configuration items alternatives used the rules presented in **Table 6**.

A comparison of configuration item alternatives is presented in **Figure 11**.

The range of change in product structure depends on, among others, the type of function introduced to the product. In the case of a motoreducer, product function can include, e.g., enabling assembly in a particular workplace, transmitting torque, etc. Changes on functions related to product assembly in a particular workplace can, for example, be focused on changing output shaft diameter.

	4				
	3	+	+		
	2			+	
	1			+	
What? \ How?		Nominal power	Output speed	Ratio	…..
Attribute	Value	1	2	3	
Belt with	1200				
Belt speed	3		9	9	
Power	30	9			
….					
Needed delivery time	5				
Target value		30	108	14	

Figure 9. Attribute target value of feeder device driving gear.

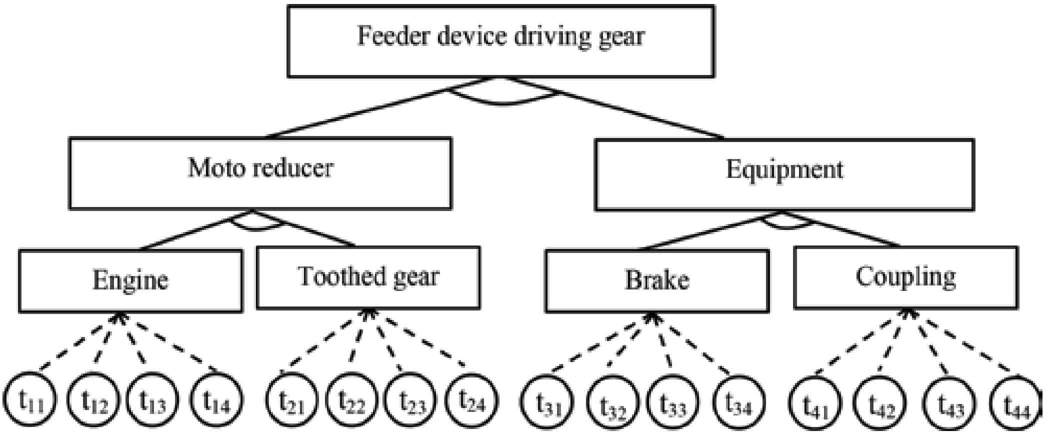

Figure 10. Feeder device driving gear structure.

Configuration items	**Alternatives**	**Attributes**		
		Power	**Speed**	**Ratio**
Toothed gear	t_{11}	33	83	18
	t_{12}	32	50	20
	t_{13}	33	94	16
	t_{14}	35	56	18
Engine	t_{21}	30		
	t_{22}	35		
	t_{23}	40		
	t_{24}	35		

Table 3. Feeder device driving gear—Configuration item alternative characteristics.

Configuration items	**Alternatives**	**Attributes w_{kzt} coefficient calculation**					
		Power	w_{k1}	**Speed**	w_{k2}	**Ratio**	w_{k3}
Toothed gear	t_{11}	33	10,00	83	23,15	18	28,57
	t_{12}	32	6,67	50	53,70	20	42,86
	t_{13}	33	10,00	94	12,96	16	14,29
	t_{14}	35	16,67	56	48,15	18	28,57
Engine	t_{21}	30	0,00				
	t_{22}	35	16,67				
	t_{23}	40	33,33				
	t_{24}	35	16,67				

Table 4. Configuration items—Indicator of w_{kzt} calculation.

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Configuration items	Alternatives	Attributes grade						
		Power	**Grade**	**Output speed**	**Grade**	**Ratio**	**Grade**	**Overall grade**
Toothed gear	t_{11}	33	4	83	2	18	2	2,67
	t_{12}	32	4	50	1	20	2	2,33
	t_{13}	33	4	94	3	16	3	3,33
	t_{14}	35	3	56	2	18	2	2,33
Engine	t_{21}	30	5					5
	t_{22}	35	3					3
	t_{23}	40	2					2
	t_{24}	35	3					3

Table 5. Configuration item variants, partial assessment s_{kzt}.

	Assessment indicator		Assessment grade
If	$w_{kzt} \leq 5$	Then	$s_{kzt} = 5$
	$5 < w_{kzt} \leq 10$		$s_{kzt} = 4$
	$10 < w_{kzt} \leq 20$		$s_{kzt} = 3$
	$20 < w_{kzt} \leq 50$		$s_{kzt} = 2$
	$50 < w_{kzt}$		$s_{kzt} = 1$

Table 6. An example of assessment rules.

What?	How?		Toothed gear	Engine
Attribute	Value		1	2
Power	30		9	3
Output speed	108		9	
Ratio	14		9	
....				
Delivery time	5 week			
	Grade	1		
		2		t_{23}
		3	$t_{11}, t_{12}, t_{13}, t_{14}$	t_{22}, t_{24}
		4		
		5		t_{21}

Figure 11. Configuration item assessment in QFD matrix.

The presented product configuration algorithm helps to identify product attributes and compare and select product components. It is based on the following assumptions [32]:

- The product can be divided into configuration items which are components, modules or parts with a modular structure.
- There exist some alternatives of the configuration items.
- Enterprise staff is experienced in product adaptation according to individual customer requirements.

4. Conclusions

In basic applications QFD uses human knowledge. The presented approach is focused on developing a QFD-KB knowledge base, which is able to support human decisions related to product configuration. The presented algorithm joins methods of knowledge representation and supports decisions related to identifying and assessing product configuration items, such as components, modules and parts. In the presented QFD-KB, attributes analyzed by customer and producer are related to one another with the QFD matrix.

Methods of knowledge representation, such as procedures, rules, ANN and CBR are useful in the presented QFD-KB. The presented approach uses advantages and avoids disadvantages of different methods of knowledge representation. Selection of the proper knowledge representation method determines the effectiveness of QFD-KB.

Integration of the knowledge related to customer requirements, product structure and the manufacturing process helps to assess product characteristics in make-to-order product offer preparation.

The proposed algorithm of product configuration uses the QFD method and performs comparison and evaluation of configuration item variants, as well as missing data estimation related to the production process of product redesign.

Product configuration requires knowledge related to, among others, product structure, manufacturing process and potential failure problems.

Product configuration efforts are focused on the following categories:

- Collection of rules related to product selection and redesign
- Collection of facts about products functions and their structure
- Collection of facts and rules regarding product manufacturing variants, possible failures, timing and costing

The decision process regarding product configuration, which is focused on compatibility between customer requirements and functional and physical product features, can be supported with the use of QFD-KB for product configuration.

Conflict of interest

There is no conflict of interest.

Author details

Izabela Kutschenreiter-Praszkiewicz

Address all correspondence to: ipraszkiewicz@ath.bielsko.pl

University of Bielsko-Biala, Bielsko-Biała, Poland

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Chapter 5

Testing and PLM: Connecting Process and Product Models in Product Development

Khadija Tahera and Christopher Earl

Additional information is available at the end of the chapter

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Abstract

The product lifecycle management (PLM) is the process of managing the entire lifecycle of a product from the idea generation, through the design, development and manufacturing to service and disposal of the product. Testing often is considered to be an activity to perform during the product design and development phase. However, the information about how a product is designed and tested is useful for designing the maintenance and the monitoring and maintenance data can provide useful information in developing the next generation of a new product. The main objective of this chapter is to understand how testing process in integrated into the product lifecycle. This chapter reports a case study in a UK based manufacturing company and based on that develops a framework to highlight the importance of testing. Also, proposes a conceptual model of how testing activities can be managed in the product lifecycle management process.

Keywords: product development process, testing, computer aided engineering (CAE) analysis, design for maintenance, product description

1. Introduction

During a product development process, information becomes available to, and is requested by, many partners, design teams and organisations. Information about properties and performance of components and subsystems is the basis of decisions made in the development process. This information has many sources ranging from mathematical models, simulations, testing of physical models and prototypes and customer use data. It has many destinations, in the primary design phase and then through the product life in operations of maintenance, refit and redesign. Product Lifecycle Management (PLM) is primarily concerned to create product models to cover the full range of processes, operations and activities required to support a product through its lifecycle. A critical and current issue is the extent that these product models provide the basis for generating corresponding process models particularly dynamically so that process models continuously reflect the current state of the product models [1]. One aim is to enhance through improvements in workflow for planning product development processes, the significant gains that PLM systems have delivered over a period of 25 years in reducing both the duration and costs of product development [2]. Research by the authors [3, 4] has concentrated on the processes of testing and their ubiquity through product development. Critical testing processes such as field testing ([2], for example) are identified in these workflows, which deliver product development. However, the way that these testing processes form a critical part of all the processes from start to finish of the product lifecycle, whether as inputs, as drivers for iteration, for establishing alignment to regulations or for confirmation of completion of a satisfactory design, has received limited consideration in the literature. Tests are long and expensive activities and most product development activities and tasks depend on the results of test, whether, physical test, simulations or field data gathered during customer operations. This chapter examines methods to integrate testing more closely with other product development processes as well as to improve the planning of the processes of testing so that testing activities are scheduled optimally. Further, the chapter examines how the results of tests can be applied to assist other product development processes. Critically, it analyses how preliminary test results can be of significant assistance to these other processes, speeding their completion.

Previous research by the authors has addressed two particular issues. First, combining information from both physical and virtual testing (simulation) can bring forward in time the availability of a workable product model suitable for the next design stage [3]. This helps planning a design process in an iterative cycle of proposal, test and redesign through developing a method to analyse the overlap between steps in this cycle and optimise this overlap to reduce overall development time. In particular, the long duration of some physical tests, which are necessary to ensure performance and conformance to regulations and standards, are a bottleneck in product development. Starting downstream design activities dependent on these tests before the tests are completed can ease this bottleneck. Essentially, the proposed method applies information from two distinct product models, simulation and physical test to change the process model, allowing significant overlap between activities. The method relies on observing the degree of convergence between simulation and test data.

The second piece of research [4, 5] examines more closely how testing activities can be explicitly integrated into the product development process for complex engineering products. This research highlights the mismatch between several models of product development which tend to relegate testing to be an activity late in the design process or primarily concerned with quality issues. In fact, examination of practice shows that testing is integrated throughout. The misconception in product development process models has possibly arisen because the long duration of physical tests means that the results of testing are not available until later stages, although the activity itself necessarily starts early in the process. This research therefore points to a significant reappraisal of appropriate process models resulting from how data is available in product models. Both strands of previous research have focused on testing for design, rather than wider product development through lifecycle. However, they provide useful insights into the relationship between the product models of PLM [1, 2] and the process models [6] in product development.

This chapter applies the results of this research to integrate testing and design more widely in the product lifecycle. Section 2 introduces some background and literature of PLM with particular reference to testing. Testing is considered from a general perspective as activities which analyse properties and performance of designs. A short review of existing research on the relationship between testing and PLM in Section 3 covers the mixes of testing activities at various stages of the product lifecycle based on some industry observations. Section 4 extends the proposition, first proposed by Tahera et al. [3] for testing and design, and reviews a three-way mix of testing types comprising simulation, use data (from embedded product monitoring) and physical testing. Further, wider implications of these methods are drawn in Section 5, especially in how PLM systems coordinate product models generated through design, testing and product monitoring activities. Section 6 discusses the tentative nature of these findings, the requirements for further research and the potential benefits for PLM systems. In particular, the refinements in process models recognise testing activities explicitly and their close integration with other processes in product development. Changes in process models drive changes to product models and PLM. This research does not cover the latter stages [as referred as End of life (EOL)] of product lifecycle.

2. PLM data and descriptions

Two observations are relevant when considering testing in product lifecycle. First, testing is a continuing activity, whether physical or virtual, throughout lifecycle. Testing data sets up maintenance schedules and product use data assists in updating these schedules. Periodic refit and redesign may emerge from testing new materials, components and subsystems to track upgrades and changes to customer requirements.

Second, testing supplies information which becomes part of a product description. PLM systems handle several product descriptions [7, 8] and a major challenge is maintaining consistency and integrity of multiple descriptions In the simple case this might mean ensuring that changes to a design in one description, perhaps CAD geometry, are propagated accurately to descriptions for manufacture and assembly such as BoMs and tolerancing schemes. Results of testing update these multiple descriptions in PLM systems. As observed above, testing takes place continuously through product development and product use. However, the schedules for physical testing activities have long duration.

Product performance data is gathered over a range of use conditions and longitudinally over time. Data of two types is relevant in testing. Special tests can be set to investigate particular characteristics such as thermal dynamics of an engine which formed one of the areas of previous research [3]. Other data is gathered from product monitoring in the field. Increasingly the latter data, which may include component wear, degradation in performance or replacement of components, for determining preventative maintenance or redesign of failing components, is well established for complex products such as aerospace [9]. However, quick and effective use of this testing data depends on levels of confidence when only partial data is available. A similar situation to testing in the initial stages [3] occurs throughout lifecycle, where reliable decisions on maintenance, retrofit and redesign when taken early can reduce operational product cost to customers as well as more speedily remove potential causes of failure.

The broader challenge for PLM systems with their multiple decisions of different aspects of a product is two-fold. **Figure 1** indicates these two broad challenges as updating performance and product descriptions iteratively. The first is to ensure that testing data updates performance and operational user descriptions consistently. The second occurs, when testing or use monitoring data prompts component or subsystem redesign. The underlying configurational product descriptions such as (Bill of materials) BoMs for manufacture and assembly will change accordingly, and updating these new product descriptions consistently is critical. With the focus of this chapter on the interplay of simulations, physical testing and monitoring data, it is noted that simulations depend on design descriptions and that inconsistent descriptions will reduce the accuracy of simulations leading to slower alignment between the results of simulations and the results from physical test. PLM has a design focused view in which the processes of product development effectively 'call for' testing and monitoring to validate and verify a design proposal. A critical circumstance in product lifecycle is the incorporation of new technologies in components and systems. Testing is often mandatory to meet regulations before new components can be fitted and operated, especially for complex products in the automotive and aerospace sectors which have a long service life. Conversely it is suggested here that a testing and use data view of PLM can drive design. It is argued that testing and design are equal partners in the product development process and promoting closer integration through PLM will give competitive advantage. This chapter explores how product development teams can reduce redesign iteration cycle time at several points in the product lifecycle. Incremental reductions in product cost and improvements in customer service at each cycle accumulate as the number of cycles increases yielding a significant benefits over the whole lifecycle.

Several pieces of research have examined how early availability of data from testing can reduce overall design duration [10–12]. However, these methods generally take an abstract perspective looking at optimising a given set of design and testing activities. However, they do not

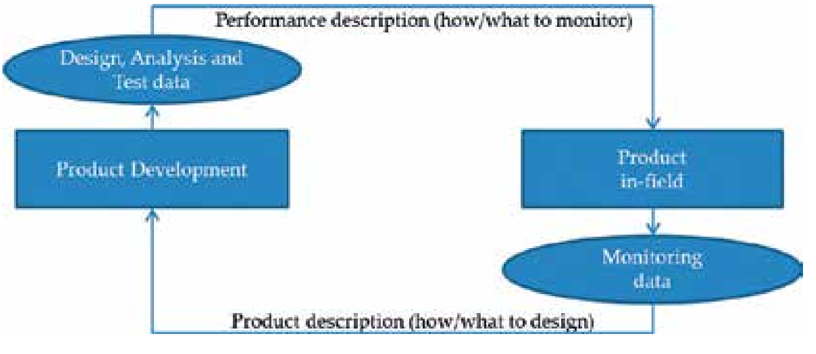

Figure 1. Iterative updating of product and performance descriptions.

really question the assumed relationship between design (generally interventions in product such as design, maintenance or retrofit) and testing (generally derived data from analysis, simulation, physical test, or product use monitoring). Previous research [3] has examined the relationship between design and testing in their narrow senses and concluded that rebalancing leads to a more feasible and realistic model of process. Data from testing (in the wider sense throughout lifecycle) is expensive and time consuming to provide. How and when it is used is a critical part of process models. Conversely these descriptions of performance and functionality derived from testing require support from PLM alongside descriptions of product components, configurations and architectures derived from design activities [13].

Dynamic process models have been identified as critical to delivering the benefits of PLM systems [1, 14]. Methods to construct evolving process models from PLM product models use Design Structure Matrices and workflow networks. This research theme presents a new framework for PLM systems so that they can support these evolving process models. Conversely, process models which highlight the balance (and integration) of design and testing (in their wider senses outlined above) assist in the construction of product models in PLM systems.

Figure 2 presents a generic sequential process model [1] of the stages of a product's lifecycle from identifying market needs to recycling. This also represents the overall information flows in product lifecycle.

Another view of information flow within product lifecycle is presented in **Figure 3** adopted from [15], which consists of three main phases: beginning of life (BOL) includes idea generation, product development and production, middle of life (MOL), includes use, service and maintenance and end of life (EOL) comprises of reuse, recycle and disposal.

At every stage of the product lifecycle, information such as design specification, Computer Aided Design (CAD) drawings, Computer aided Engineering (CAE), physical test results and technical documents are generated [16]. These pieces of information are captured, stored, managed, and transferred between different people and application system during product lifecycle management. In general, PLM includes the planning, execution, control, and documentation of all processes in the product lifecycle [17]. Information flow from the BOL phase to other phases is managed through several information systems, such CAD tools, product data management (PDM) and knowledge management (KM). However, the information flow from/to MOL and EOL is not well supported or managed through current tools and information systems, therefore the critical information from these phases about product use data often do not adequately feedback to the BOL phase [17]. This may cause the decision- making process in the product lifecycle to be inaccurate and incomplete.

Different descriptions make up a product model in PLM. These are created during stages of the product lifecycle to facilitate the next stage of the process. The descriptions of product,

Figure 2. Development process model (taken from [1]).

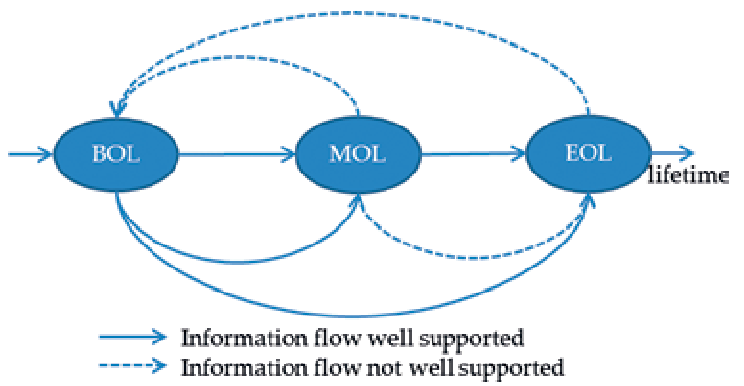

Figure 3. Levels of information flow achieved between the different product lifecycle phases [15].

design and performance are particularly relevant for PLM management. The definitions for these descriptions vary and for this research the following definitions are adopted.

Product description is the explicit result of a design process, which is the information for defining the product [18] usually in the form of drawings and CAD models. Design information is of two types. First, background information, such as the design requirements, design methods and design standards and second foreground information on the details of the product. The latter is the product description. *Design description* covers the information from which the product can be manufactured [19]. *Performance description* is the realistic system-level performance description. This can be based on several different physical models. For example, heterogeneous models covering mechanical, fluid and electronic dimensions are needed to describe the performance of complex products [20].

3. Testing across product lifecycle: an industry example

This section outlines testing and associated activities at various stages of the product lifecycle as observed in a major international company which designs and manufactures automotive diesel engines. First, the company-based product lifecycle management process model is described. Next, types and sequencing of testing in the product development process of the company is examined. The scope of testing is then broadened to include other aspects of PLM, especially maintenance and new generation product design.

It is a UK based diesel engine design and manufacturing company, that offers a wide range of diesel and gas engines and power packages from 8.2 kW to 1886 kW and has the capacity to produce up to 800,000 units per year. There are product families with different power ranges to meet the requirements from different markets. Products also vary in families depending on the number of cylinders, aspiration and control mechanism. **Figure 4** shows the series of engines in the company's product range. Eighteen semi-structured interviews were carried out at the company premises from February 2011 to February 2014. Eight engineers including a senior engineer, a development engineer, a business manager, a verification and validation

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Figure 4. Company's product range (taken from [4]).

manager and a validation team leader were interviewed. The case studies involved a series of interviews ranging from 40 to 180 minutes in duration.

Figure 5 presents the view of the diesel engine company on their product lifecycle management process model. The top layer of the model shows key stages of the product lifecycle from the business strategy to the disposal of the product. The beginning, middle and end of life (BOL, MOL, EOL) classification, introduced in Section 2, is shown on the bottom layer. The middle layers show key activities that are undertaken during the stages of product

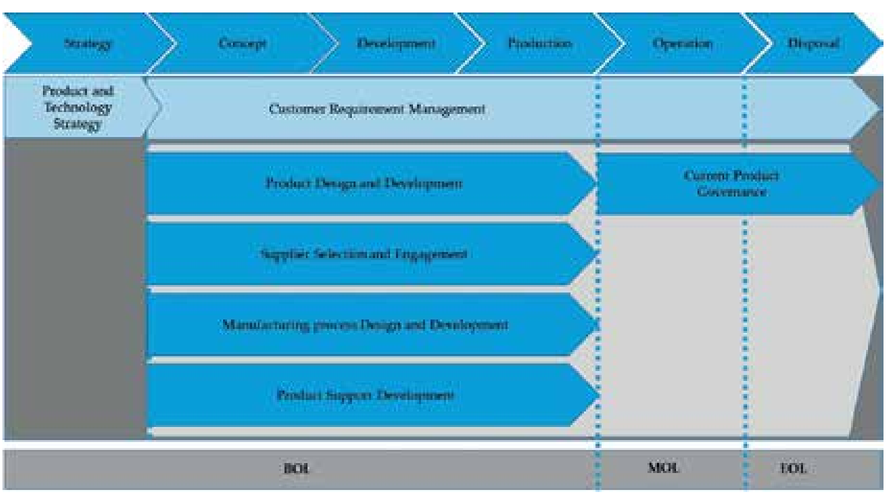

Figure 5. Product lifecycle management process model.

development. Although, this chapter will only discuss the product design and development activities but it is important to highlight that development of the company's product support starts in parallel with product design and development. Further, to aid support, the product is monitored by the company during its operation and up to its disposal.

3.1. PLM process model

The company's product development process mainly comprises two wide-ranging processes; the New Technology Introduction (NTI) process and the New Product Introduction (NPI) process. The general research and development exercise occurs through New Technology Induction (NTI) process in their research and Development (R&D) department before the NPI process starts. Emission-related legislation is a key driver in technology development for this company. New technology, for instance, an after-treatment system that will reduce engine emission, would be developed in the NTI stage, and this system would be integrated with the engine through NPI process. This chapter focuses on the NPI process as most directly aligned with generic product development and PLM. However, it is noted that the background processes of NTI critical in product lifecycle especially as new technologies come on stream during life, enabling redesign and retrofitting of new components and subsystems.

As shown in **Figure 6**, this NPI process in the company has seven stages starting from the identification of market needs to the review of a product's performance in the field, i.e. "Requirements" to the "Review of Market Performance" (see Tahera [4] for further details of the company processes). Each stage leads to a formal gate review. Based on prescribed criteria, a product must pass through review at the gateways (GW1, GW2,…GW7) before the product development project proceeds to the next stage.

Testing and the key activities of design, computer aided design and engineering (CAE), and procurement of prototypes are considered in this study. The latter is a major activity since these need specialist design and manufacturing expertise, often involving new manufacturing processes, materials and technologies. A more detailed flow diagram of these stages is presented in **Figure 6** to show the integration of the key activities.

As the diesel engine is a mature product and design changes happen incrementally, engineers in the company start with an existing analysis of the previous generation of products. For a new product introduction (NPI) programme, product objectives are checked against a current product issues (CPI) database. The CPI database provides information about failure modes and effects of current products, which will need special attention for next generation products. This process is carried out by lead team members who are the technical specialists, component owners, design owners and the verification and validation managers.

The NPI process starts in the requirement gathering phase, and should be finished before Gateway 1 (GW1), i.e. before the concept demonstration phase, however spread across the SD phase. Initially, the design alternatives are included in the analysis, because selection of a design is made based on the risk with that particular design and the associated time and cost of its validation program. All design options are considered during this phase. These help to analyse the trade-offs that can be made across different design options. If this analysis

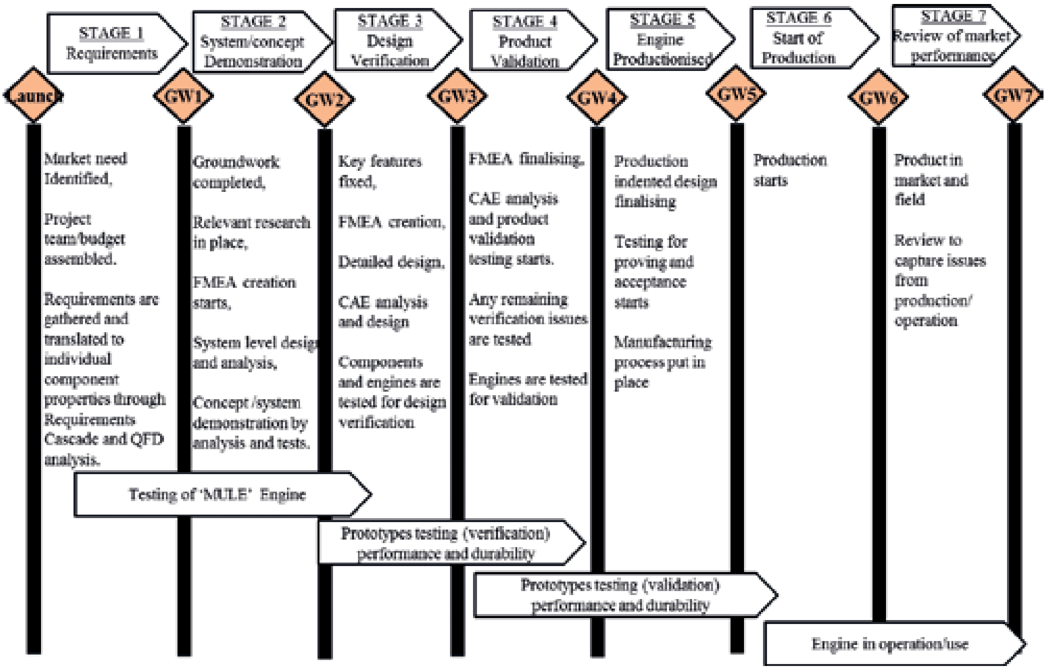

Figure 6. Stage-gate process for new product introduction in a company study.

identifies high risks in design decisions, CAE analysis and design changes are undertaken until the risk is reduced to an acceptable level to proceed with the project. These CAE analyses typically fall into three main areas: structural analysis, mechanism or dynamic analysis and thermo-fluid-flow dynamics. They result in the determination of parameters like material properties, geometric idealisation, and physics, which help to define the scope of the design activity. When the overall risks are assessed, design verification and validation actions are decided and planned to mitigate risk. Verification and validation activities can range from design changes, further CAE analysis to testing.

Ideally, most of the development related testing should start after the requirements have been identified i.e. after the Gateway 1 (GW1) and continue till the product is validated, i.e. until Gateway 5 (GW5), after which the engine is released to production. However, as depicted in **Figure 6**, these testing activities can spread further across subsequent stages of the process. At each stage, functional tests include the performance and emission (P&E) tests and mechanical tests for durability and reliability. Performance testing measures engines properties. For example, power and fuel consumption of an engine may be measured given a regulated fuel and air intake into the engine cylinder under steady state conditions of constant speed and load. While ensuring the performance, engines need to satisfy legislative conditions, for instance, the chemical constitution of the exhaust gases. The durability and reliability tests are conducted in peak harshness and tougher condition for a reasonably short period of time, called accelerated tests, forcing components or engine to fail/pass. For example, a gross thermal test procedure specifies the test cycle for determining the thermal fatigue resistance of core engine components. Typically, performance and emission related tests are performed before the mechanical durability and reliability testing.

Testing occurs at different levels of the product. Component level testing happens primarily at suppliers of components, although the case study company also carries out testing to investigate areas of design concern. Engine level testing involves standalone engines on a test bed. Machine level testing involves engines mounted in a machine or vehicle to reproduce expected conditions of use. **Figure 7** indicates how engine level and machine level testing are mainly conducted in parallel in the three consecutive stages, for different purposes in the product development and PLM. The stages are characterised by the type of testing activity. Stage 2 has Concept/System Demonstration (SD), stage 3 has Design Verification (DV), stage 4 has Product Validation (PV) and stages 5 and 6 focus on Certification.

Concept/system demonstration (SD) testing is primarily to demonstrate 'performance capability'. It shows that the technology can deliver the required performance. Alternative concepts are analysed and evaluated at this phase. A combination of old and new parts are built into an engine called a MULE. This MULE engine is tested to verify the performance of new parts.

Design verification (DV) is primarily to develop optimal performance and validate hardware at the optimised performance. The aim is to ensure that design outputs meet the given requirements under different use conditions. At this stage, testing focuses on the verification of a chosen design, through detailed analysis and testing of stress, strength, heat transfer and thermodynamics etc. This stage validates the hardware prior to commitment to expensive production tooling.

Product validation (PV) checks the effect of production variability on performance and any remaining hardware variation. This phase performs hardware testing which is limited to late design changes and emissions conformance testing. In this phase, detailed testing for reliability and durability occurs and the intended product is validated. The mandatory tests required for compliance usually occur during PV phases.

Testing for certification happens in stages 5 and 6 before product is released to customers. Global emission regulations for diesel engine manufacturers provide requirements for the testing and evaluation of new components and new engine designs. It is an imperative for certification that the company follows the standard regulations during product development in terms of how a product needs to build and tested during validation for certification. For instance, to meet the in-use compliance, the company needs to demonstrate that the engine will meet specific levels of particulate emissions that will be detected and measured at the end of the useful life of the product.

The case study company considers that testing of their product continues into use. As one senior engineer in the company remarked "*in fact, real tests start when products are in use*". Their engines are equipped with a remote monitoring system that allows them to capture and collect field data. They have special user groups and they have established close relationship with consumers who help to collect more reliable data. The data consists of equipment

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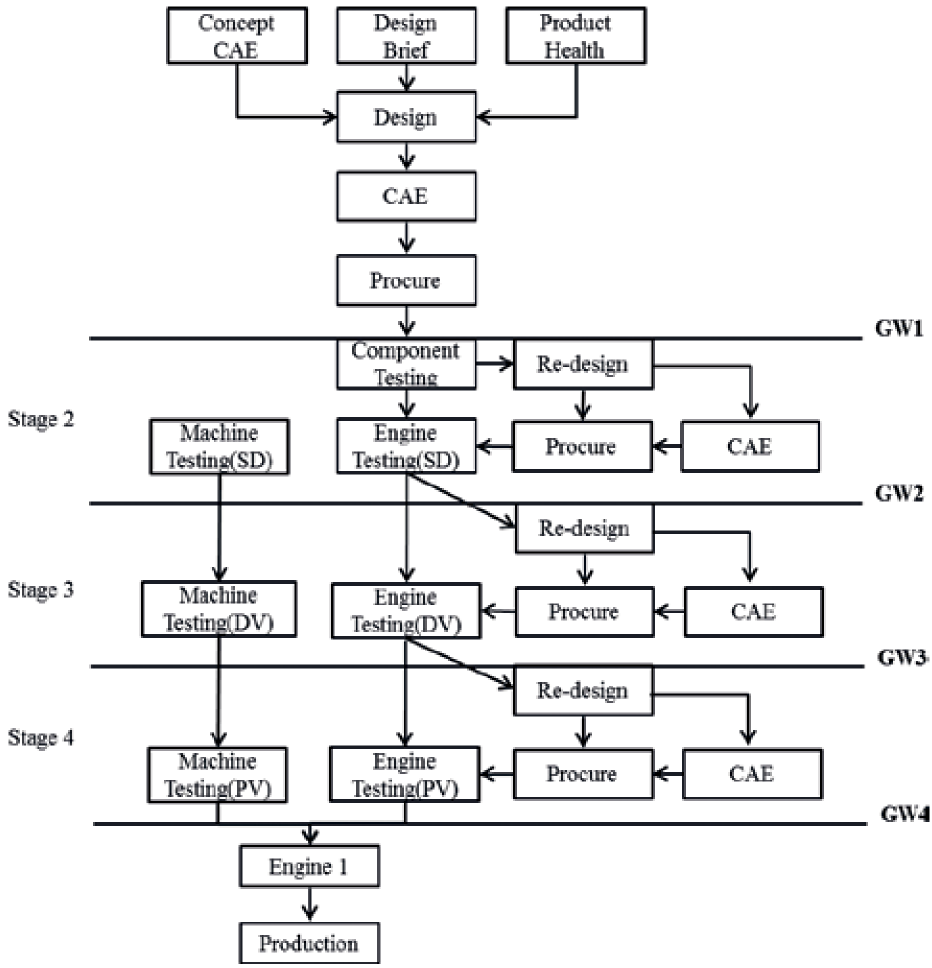

Figure 7. Flow diagram of testing and associated activities in diesel engine design and manufacture (adapted from [4]).

characteristics identification data, usually the unique numbers, operating data (engine on/off and physical variables), event data (failure and maintenance history) and environmental and condition data. These field data are useful for several reasons:

1. to monitor: how a product is used by a specific customer groups to identify any inappropriate and misuse,
2. to monitor the current health of the product to plan and design their aftermarket service, i.e. repairs and maintenance services.
3. to feedback to the beginning of the lifecycle as the product health monitoring data are the key input for designing the next generation of the product. This enables a reliable specification for the design phase and the development of a product description.

To help deliver these benefits the company creates two descriptions for monitoring and new product development in addition to the PLM descriptions mentioned in Section 2 for product, design and performance:

i. Current product governance—during product in operation/ field data to help new product development,

ii. Product support development—during product development to help product monitoring.

3.2. Current product governance: field data and new products

In the diesel engine company, the 'voice of the customer' (VOC) is captured in many ways: directly, through discussions, interviews and workshops with customers, and indirectly through analysing customer specifications, warranty data, and field reports etc. and through dealers and distributor channels. Quality Functional Deployment (QFD) is applied to identify critical technical requirements of the design which will need verification and validation by testing.

The company uses Failure Modes and Effects Analysis (FMEA) to evaluate a potential design for possible failures and to prevent them by proactively changing the design rather than reacting to adverse events after failures have occurred. This emphasis on prevention may reduce risk of failure in field. FMEA is particularly useful in evaluating a New Product Introduction programme prior to implementation as well as in assessing the impact of a proposed change to an existing design. More details about FMEA and steps of FMEA analysis can be found in [21]. FMEA is one of the most widespread methods used in determining priorities for technical risks in the PD process especially during the testing phase [22].

To identify the potential effects, the company reviews documents, including historical data, warranty documents, field service data, and customers' complaints. The company rates the severity of the effects of a failure mode. Any failure occurring in the field is considered as a high risk. Issues identified in use significantly drive next generation product development and testing procedures. The company continuously monitors and captures a product's performance and durability when engines are used in a field. For a new product development, the company uses information from the 'use in the field' to assess how the product is performing and from the 'use of the customer' (how customers are using the product) to judge when a potential failure is likely to occur.

Field data is particularly valuable as it consists of information about failures and repair actions that have been taken place under real operating conditions. This enables the acquisition of statistically significant reliability and repair data [23]. Issues in recording field incidents are addressed by Smith [23] particularly how reliance on people means that recording is subject to errors, omissions and misinterpretation.

3.3. Product support development: design for maintainability

Maintainability is characterised as the ease of retaining or restoring a product in effective use conditions by using specific procedures and resources [24]. It is an important factor in the economic success of an engineering system. "Design for maintainability requires an evaluation of the accessibility and reparability of the inherent systems and their related equipment in the event of failure, as well as of integrated systems shutdown during planned maintenance" [25]. Maintainability procedures and techniques not only avoid and fix failures they also consider how a system might fail. Three types of maintenance can be distinguished: breakdown maintenance (corrective maintenance), preventive maintenance, and predictive maintenance (condition-based maintenance).

Condition monitoring and fault diagnosis techniques are used for predictive maintenance [26]. Product health monitoring is a research area that covers failure detection, current health assessment and remaining useful life prediction [26, 27]. According to Fu et al. [28], most failures do not occur instantaneously. There is degradation and associated symptoms before the actual failure. The main objective of the predictive maintenance is to reliably identify these degradation processes so that maintenance can be affected before the actual breakdown. Predictive maintenance is based on the product's performance and condition monitoring data. For example, in well-established methods, vibration data is analysed to find the frequency responses to identify the type of fault present in the equipment [27].

At the design and development design stage the main characteristics of a product are determined and product performance is evaluated. Therefore, design for maintainability should be considered during the product development. However, according to Coulibaly et al. [29], there is lack of an efficient tool for considering maintainability and serviceability at the early design. Also, there is limited research on how information from design, CAE and tests can support product maintenance.

Kiritsis et al. [30] have commented that clear definition of the information for maintenance is required if appropriate and adequate information is to be collected. Usually, data collected during Middle of Life (MOL) phase of product is for maintenance management purposes and may not be appropriate for feeding back to the Beginning of Life (BOL) phase to redesign or improve a product. Although people involved in this process often have a clear understanding of the required information, it is not straightforward to define or determine exactly what information will be required.

A baseline performance description would allow degradation over a period of use to be assessed. As mentioned before, advanced engineering products such as the diesel engines studied here are equipped with instruments such as sensors, meters, controllers, and computational devices and have the processing capacity to self-detect/ predict certain problems. Next section proposes a conceptual model to facilitate this process. Design and testing data from the EOL stages can be a useful reference point for comparing with monitoring data for predictive maintenance. Also, this model can help to clearly define the information required to be collected to comparison.

4. Extending the proposition: testing data for predictive maintenance

This section extends a method for managing the iteration of design and testing during the product development stage [3] to predictive maintenance during the product use phase. First, the previous work will be described briefly, then how the work can be extended for the purpose of the predictive maintenance will be explained.

In an iterative design and testing process, testing results usually drive the subsequent re(design) activities. A control system analogy can be used to describe an iterative design and testing process. A control system monitors, compares and adjusts at a sequence of time points. A monitoring device makes a measurement, and reports it to the comparator, which compares it with the pre-determined desired value. A decision rule uses the result from the comparator to adjust an effector. Similarly, in a test, actual measurements of a parameter are taken and compared with pre-determined values identified in design analysis to identify if the design is satisfactory.

During a lengthy durability test, for example in a "Deterioration Factor" test, intermediary test measurements are taken at a sequence of time points between start t_s and finish t_f (t_s, t_1, $t_{2\ldots}t_{n\ldots}t_f$), as in **Figure 7**. Engineers know that the performance of an engine will change over the time and they allow an acceptable margin for each time point. This is illustrated in **Figure 8** with a range of expected values specified by design and CAE prior to the test. Engineers will know how much they expect the product to deteriorate after say 200 or 500 hours of running the test. If the product deteriorates below an allowable limit, or margin, at that time, then it is deemed under-designed. If an engine performs above the margin then it is assumed to be over-designed. Therefore, if the engine produces any value under or above the expected values (including margins) then these deviations are not acceptable (see **Figure 8**) and indicate that redesign is required. 'Deviation' is the difference between the expected value of a parameter and an actual measurement of that parameter, at the time of an assessment (e.g. test).

Figure 9 shows a schematic, which presents a simplified case of **Figure 8** in which the expected value is a single value rather than a range. In practice this might be the mean of the distribution of expected values and is represented as the upper straight line (in red). The lower line (in green) represents the measured values. A physical test starts at t_s and finishes at t_f. Since the design meets specification based on the best knowledge available at t_s, (or rather there is no information to indicate that it does not) the red and green line meet at t_s. During the testing process, test measurements are taken and the actual value of a parameter at any point is identified.

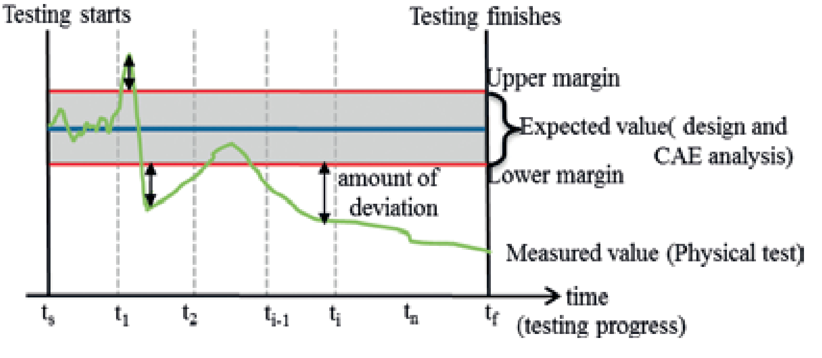

Figure 8. A schematic of expected and measured value and associated deviations at different times during a test.

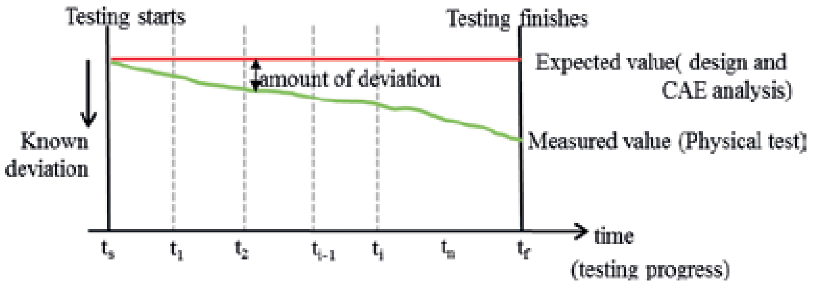

Figure 9. A simplified model of deviations between expected and measured values during a test.

Deviation, at a time point, is identified as the difference between test measurements and expected value. The magnitude of the deviation is shown with a double-headed arrow in **Figure 10** which depicts a case of under-design, with measured product performance gradually degrading and the deviation increasing monotonically. This considerable simplification is an assumption of the model developed here. The sloping line represents the evolution of test results over time, which tends to show increases in deviation of the design from expected performance. The deviation does not, in practice, decline linearly.

The difference between test measurements at different times, can reveal the 'degree of evolution' [12], i.e. how fast the deviation is changing in approach to the final value of the deviation at t_f. Details can be found in [12].

A similar proposition can be used for predictive maintenance. The design stage identifies the expected product performance in use, i.e. a range of expected values of a parameter can be specified by design, CAE and tests during the development stages. Product's health measurements are taken at a sequence of time points between start t_s and finish t_f (t_s, t_1, t_2 …..t_n….t_f), as in **Figure 9**. Using a similar approach as explained above, the "amount of deviation" and the 'degree of evolution' can identified.

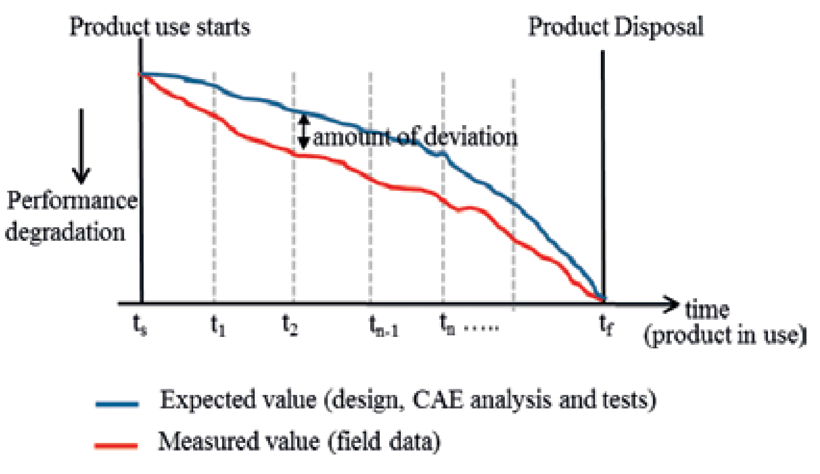

Figure 10. Comparison of CAE and test data with field data to identify product's performance level.

Once, these two factors are identified, i.e. how fast and how much within a time interval a product is degrading can be determined, an effective maintenance plan can be made.

5. Implications of the proposed method in PLM

The extension to include user and service data, combined with CAE simulations and test data to the latter stages of the product lifecycle in maintenance schedules and the refit of critical components is straightforward. As noted above the user and service data of previous products is used extensively in initial new product development, especially in FMEA and QFD processes. With a product currently in service, a history of user data will be accumulating. This serves several purposes. First to help specify and tune the maintenance schedules. Statistically significant data will be available from a large population of products about the behaviour, performance profiles and probabilities of failure of critical components in the product. This data is at the core of establishing service schedules and swop outs for potentially failing components.

Second, failing components can be identified for redesign and refitting. The use conditions and the causes of failure may be clear from the data. The cycle of product development will be repeated with simulation, physical test, often necessary for regulation conformance, and redesign. The methods of Section 4 which allowed convergence of simulation and virtual test results with those of emerging physical tests will enable a quicker time to redesign and replacement of the failing component with corresponding significant improvements in product performance and customer satisfaction.

Third, the emergence of new technologies at high technology readiness levels means that designs which were not feasible originally, because of the risks associated with low TRL can now be incorporated into the product. The purpose is to reduce costs, both to manufacturer and to consumer of the product. This process is frequently complicated by the dependence of the product developer on the processes of a specialist supplier. The advantages of the new and now mature technologies can be assessed against the use and service data. This will determine the benefits to all parties of the new technology and thus the business and engineering pressures on timescales. With an intense pressure on speed of product improvement through new technologies, there is considerable advantage in being able to overlap test and simulation of the performance of new technology. It is noted that as these processes continue further use data is continually made available. Using targeted use data in the mix of virtual and physical testing can assist in tuning the overlap, indeed there is the opportunity to install prototype new technology components in the current product and monitor use. This may help the convergence of simulation, test and use data.

Fourth, and consequential on the third, are the benefits of retrofitting. With a new technology embedded in a redesigned component, the opportunity may arise for variants, tailored to a range of use conditions. Which variant to retrofit and the associated programme of retrofit integrated with new maintenance schedules will depend on (i) performance characteristics of the variants from test and simulation and (ii) the specialised use data to match variant to user. This integration of test and use data, can assist the optimal choice of variants.

Across these processes for maintenance, refit and retrofit, the aggregated benefits of combining physical test, simulation and use data can be considerable. This can result in reducing time to introduction of revised maintenance schedules, to designing and fitting new technologies, as well as reduced costs to manufacturers and users. When all taken together the benefits to product lifecycle accumulate and make the argument for PLM systems to provide consistent and up to date information flows in supporting these processes.

In extending the model of overlapping test and design, using convergence between data sources, to these processes in the product lifecycle several additional descriptions arise in the PLM product model. These are driven by the necessity to manage the revised processes of product lifecycle which arise from the new data and new information flows, particularly in use and service data.

New process models and new product models develop hand in hand. This section has considered how product development and support through life cycle combines test, simulation and use data. Some general issues affecting PLM product models include how to compare this field data with simulation and test, the potential effects on information flows in the process models and the application of field data from one phase of product to the development process for next generation products, where fundamental analysis of the configuration and architecture of a product is undertaken over and above retrofitting new components and new technologies to the existing products.

Comparing field data with physical test is not straight forward. Usually, the case study company uses the accelerated testing methods in which tests are conducted in peak harshness and tougher condition for a reasonably short period of time. Most of the accelerated testing is to verify that the product will perform reliably during the useful life, until it starts to wear out. Physical test results might not be readily useful for comparing with the field data as the use conditions could be different, load cycle and sensor loading location could be different, for instance, CAE analysis and virtual testing can play an important role in comparing these test and field data. CAE analysis can model and control these conditions and can focus on individual parameters. The information of CAE analysis can be disaggregated into cycles, for example. Parameters can be analysed individually if required to support decision making. Analysis of these three data, i.e. CAE analysis, physical test and field data could provide useful information for predictive maintenance, as to analysis why and how a product might fail. This may also help to record/capture field data in an appropriate manner to be used by the design engineers for the next generation of the product.

The potential implications for PLM systems of the integration of design, test and field data in making information available in preliminary form to be used by PLM for dependent activities. This effectively overlaps activities previously linearly sequenced and reduces times and costs for customers and suppliers. However, such integration comes with a significant overhead. Increased numbers of cycles of revisions to the PLM descriptions is entailed as some preliminary information although sufficient to start subsequent activities may not be enough to finish them especially when on-site assurance and regulatory conformation are necessary before customer use.

6. Discussion and further research

PLM systems assemble and manipulate product descriptions, maintaining a product model. These descriptions come from many sources in the product development process including design, simulation, test and field data. To some extent the timely availability of descriptions is dependent on the process model used to organise and manage tasks. This chapter has addressed this issue through examining how a change to process models through integrating activities has an impact on PLM descriptions.

The main argument of this chapter is delineating further the relationship between the product models of PLM and the process models for planning product development. Karniel and Reich [1] make the case that product models of PLM, updated throughout product development, have the potential to drive the planning of adaptable and dynamic processes for product development. Along with other research (e.g. [14]), they develop methods and algorithms to derive dynamic process models from the updating product models of PLM. This view gives, in a sense, a priority to the product models of PLM. The 'new paradigm' of Karniel and Reich [1] provides a critical role for PLM in planning dynamic processes. Updated product models in PLM are used to update process models. Although, in many industry contexts, available information in PLM and other information systems is necessary for the management and organisation of the dynamic processes of product development, which are by nature contingent and dependent, it is not sufficient. There are imperatives and opportunities in managing processes can drive the modes and forms of information available to PLM.

This chapter has examined one aspect of this mutual dependency between product and process models. Making changes to process models through increasing the integration of test, simulation and acquiring field data, changes the requirements for product models and associated PLM systems. This research adds to the understanding of ways that process models drive the types of PLM systems necessary to support them. It complements the extensive body of research on the how PLM systems can drive dynamic and adaptable process models for product development. Considerable further research is required both in theoretical methods and in industry cases to optimise the costly and time consuming processes of testing, simulation and field data collection as well as integrating them with PLM systems.

Author details

Khadija Tahera[1]* and Christopher Earl[2]

*Address all correspondence to: k.tahera@hud.ac.uk

1 Huddersfield University, UK

2 Open University, UK

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PLM for Supply Chain Optimization

Imane Bouhaddou

Additional information is available at the end of the chapter

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Abstract

Technological advances in science and technology information and communication in recent years have completely changed the way the enterprise functions. It works toward a collaborative relationship between the different partners of its supply chain. Thus, enterprises need to exploit the benefits of integrating supply chain actors and information sharing to improve their performances. This has led to the development of a collaborative product lifecycle management commonly known as PLM. The objective of this chapter is to propose a decision support tool based on PLM for supply chain optimization. Through this work, we conciliate two scientific communities: the one dedicated to PLM and the one relating to the problems relating to supply chain optimization.

Keywords: product lifecycle management (PLM), product design, supply chain design, optimization mathematical models, integrated logistics

1. Introduction

It is recognized that competition is shifting from "firm versus firm" perspective to "supply chain versus supply chain" perspective. Therefore, the ability to optimize the supply chain is becoming the critical issue for companies to win the competitive advantage [1].

Today, it is essential for firms to exploit the benefits associated with supply chain integration and information sharing to improve their supply chain performance [2, 3]. More efficiency can be achieved if this integration is done early in product life cycle particularly in product development process [4].

This has led to the development of systems to manage the technical data of the engineering process. It is in this context that the concept of product lifecycle management (PLM) was born [5]. We propose a methodology based on PLM to design simultaneously the product and its optimized supply chain. The description of the mathematical models optimizing each element of the supply chain is not the object of this chapter. First, we define the concept of PLM. In Section 2, we explain the need of an interface integration design, production, and supply chain. In Section 3, we present our methodology of designing the product and its supply chain. In the last section, we modeled using unified modeling language (UML) and PLM, our decision support tool for supply chain optimization.

2. Concept of PLM

PLM is above all a business strategy. It can be defined as an approach collaborative management of product information throughout its life cycle [6].

We also adopt the vision of Francis Bernard, co-founder of Dassault Systemes and creator of CATIA computer-aided design software that considers PLM is a business solution that allows simulating virtually the reality of the digital product: the complete life of the product and its environment, integrating all partners in a collaborative mode [7].

A PLM system automates and simplifies the process of developing new products. This system manages critical product information, product life cycle, and value chain. PLM systems maximize development efforts of new products and significantly increase the company's performance [8].

PLM connects employees to enable them to collaborate and centralize the process of the development of new products. It simplifies the steps by which one must pass for design and manufacture and support the products offered by the company. A PLM system organizes the development from the point of view of customer constraints, production costs, sales history, or other information about the existing products in the business [9].

3. The interface design/production/supply chain

Paviot [10] illustrated a parallel between design and production; we will add a third activity that is very useful in optimizing the costs; it is associated to the management of the supply chain; they are all activities to transform resources into products (**Figure 1**):

- During the design phase, designers must have production data (production system) and supply chain data (means and equipment available). Design teams, in order to successfully integrate all the supply chain partners in the design phase, must be able to integrate all their constraints.
- During production activities, the physical product is created from physical resources (raw materials, energy, and purchased components) and the virtual product from the design

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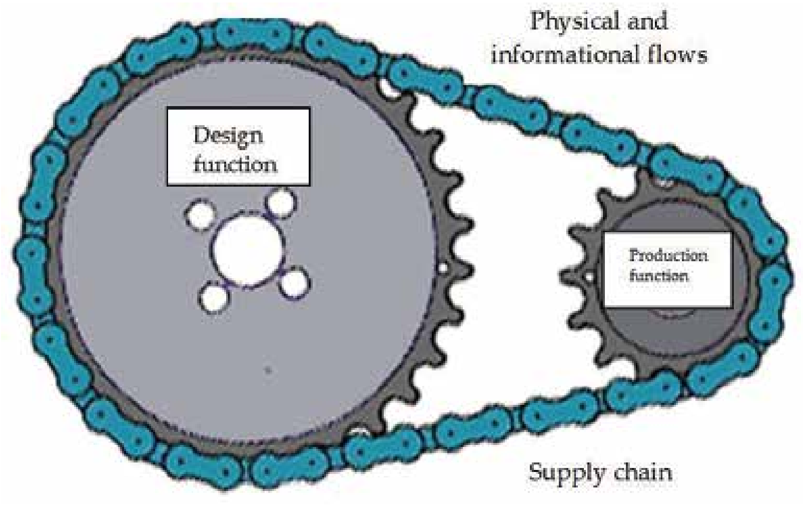

Figure 1. Design/production/supply chain interface.

(digital mockup). The production function generates knowledge that must be brought to the attention of design teams.

- During the supply chain management phase, the physical product is procured, stored, transported, and distributed using the supply chain actors (suppliers, warehouse, transport, etc.).

4. Methodology of designing the product and its supply chain

We will exploit the PLM approach in our methodology by:

- Integration of supply chain constraints into the design phase; these constraints are information flows relating to the production site, customers, suppliers, warehouses, and transport providers.
- Collaboration of all the actors of the extended enterprise (the different partners of the supply chain).
- Simultaneous design of the product and its supply chain:
- Capitalization and archiving of all data.
- Ability to make changes and modifications whenever there are changes in the general environment since a supply chain strategy based on flexibility and agility is the best approach to manage the growing pressure of supply chains [11].

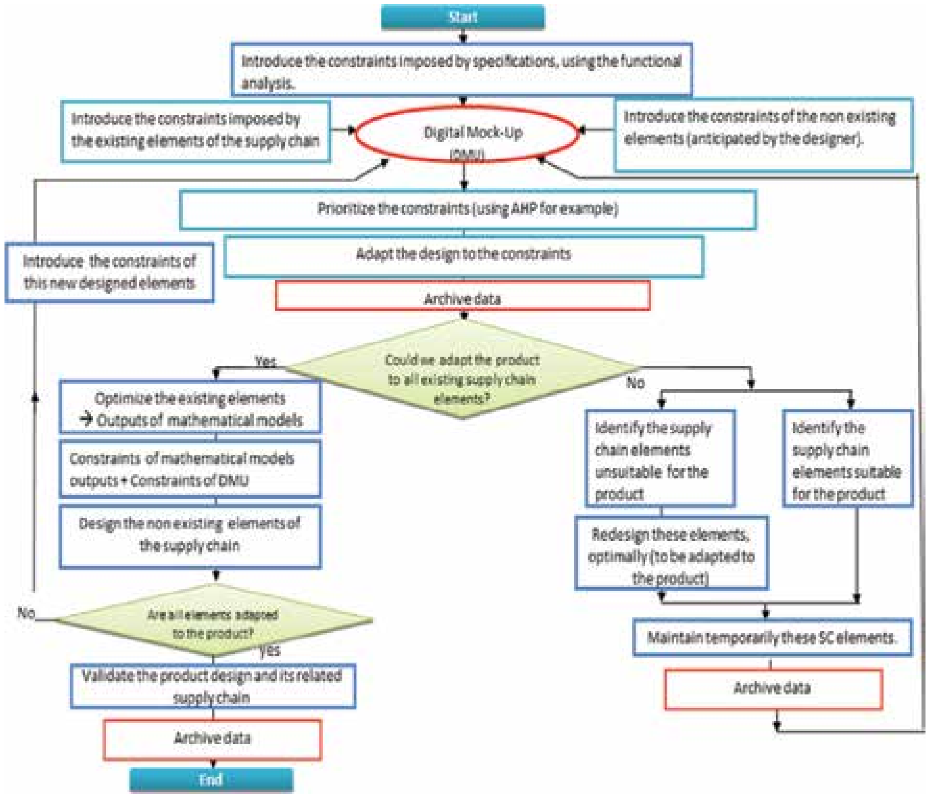

Figure 2. Flowchart of the proposed methodology.

We present in **Figure 2**, the flowchart of our methodology. As the digital mockup is the heart of PLM, it is the center of our proposed methodology flowchart, and all the operations are made around it. First, the designer receives constraints from the existing elements of the supply chain and from the customer specifications. The designer must also anticipate the constraints of the nonexisting elements (e.g., the designer should think about the transportability of the product by optimizing volume, shape, etc. even if the transporter is not yet determined). The purpose of the proposed methodology is to better adapt the product to the existing elements of the supply chain and design the rest of the supply chain optimally.

5. PLM decision support tool for supply chain optimization

5.1. Functional specifications of the tool

The proposed tool helps decision-makers with decisions about supply chain design in the product development phase [12].

We model the expected characteristics of the tool using the unified modeling language (UML) that allows the conceptualization, construction, and manipulation of data. The tool must maintain the PLM approach focused on the product; it must allow to:

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- Establish the state of the links, as well as their nature.
- Visualize the product and the supply chain and use mathematical optimization results.
- Check the relevance of each decision (objective cost respected).
- Ensure an iterative process.

The tool consists essentially of three modules that represent the main methodological steps proposed in the previous section (**Figure 3**).

Product design module: An interface must be implemented between the tool and computer-aided design (CAD) software. The designer imports a CAD file to retrieve data relating to the digital model (product nomenclature, component characteristics (physical, geometrical, etc.)).

- Supply chain design module: This module is used to represent the data relating to the various links in the supply chain. It includes fields relating to each link (supplier, manufacturer, transport, warehouse, and customer). This module allows adding or removing a link in the supply chain. It also makes it possible to visualize the succession of the links.
- Supply chain optimization module: This module is linked to an optimization software; in our case, we use CPLEX optimization software; it allows to visualize the different results of the mathematical model optimization. It will calculate the optimal product cost throughout its supply chain. This module generates the fields including the following results:
- Supplier: cost of supply and optimal quantity to supply
- Production site: cost of production, optimal quantity to produce, stock level of raw materials, and semifinished products.

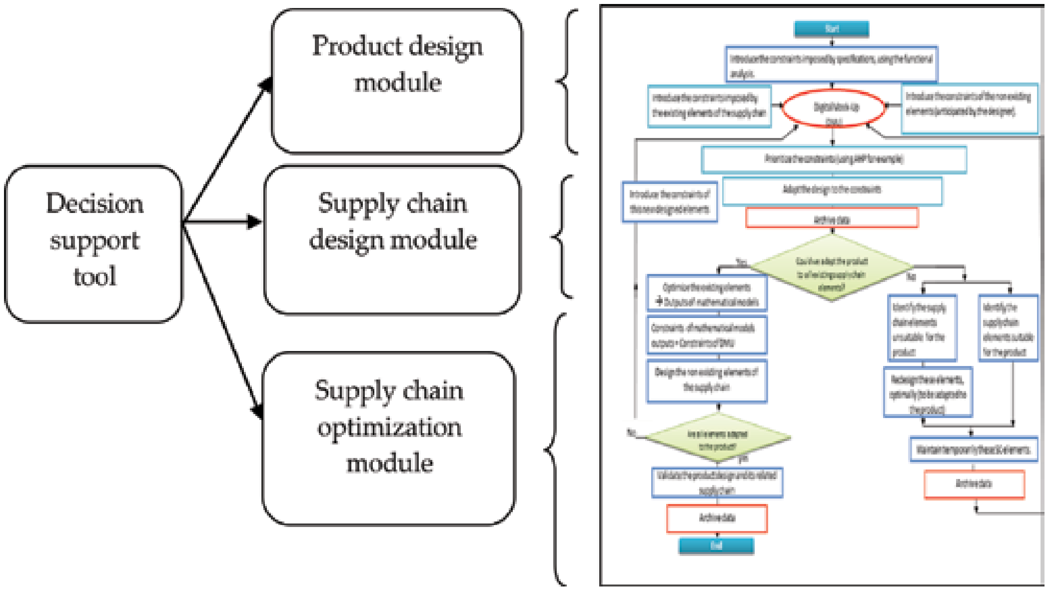

Figure 3. The three modules that make up our decision support tool.

- Transport: transport cost and optimal quantity to transport (from the production site to the warehouse and from the warehouse to the customer).
- Warehouse: cost of storage and optimal quantity to store in each warehouse.

The criteria for stopping the optimization process will be the cost of the product along the supply chain. A check with an objective cost will validate or not each design. This work is done by the decision-maker or the project manager. This person will feed the database and will be able to correctly fill in the information related to the product and the supply chain.

5.2. UML modeling

5.2.1. Use case diagrams

The use case diagram for modeling the product architecture describes the procedure for introducing all product components and their properties (**Figure 4**).

During the design phase of the supply chain, the decision-maker identifies the existing links in the chain as well as the new links to be determined. It defines the link of succession of the different links which will make it possible to specify the order in which the optimization of the supply chain will be done point by point (**Figure 5**).

Optimizing the cost of each link in the supply chain involves introducing the data relating to each link, necessary for the mathematical resolution on the CPLEX software. Once the optimization results are obtained, the cost of the product throughout its supply chain is calculated and compared to an objective reference cost. Finally, the decision-maker validates the design of the product/supply chain pair or decides to modify some links in the supply chain or to act on the product design (digital model) as shown in **Figure 6**.

5.2.2. Class diagram

This class diagram is based on our proposed methodology for the simultaneous design of product and its supply chain; it integrates the variables of the optimization mathematical models relating to each link (ou element) of the supply chain [13] (**Figure 7**).

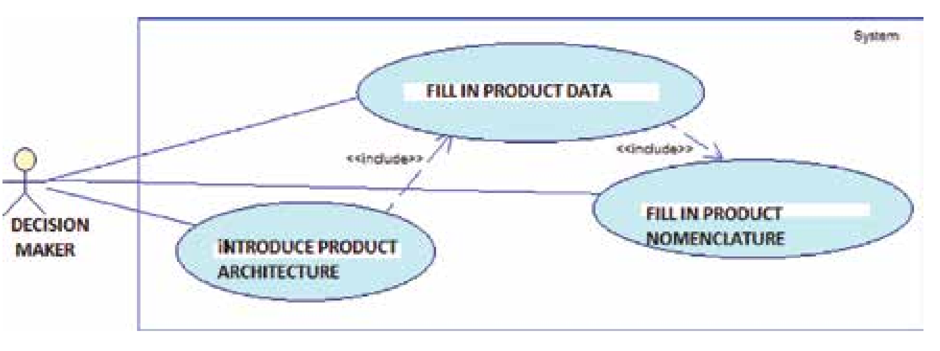

Figure 4. Use case diagram-Product architecture modeling.

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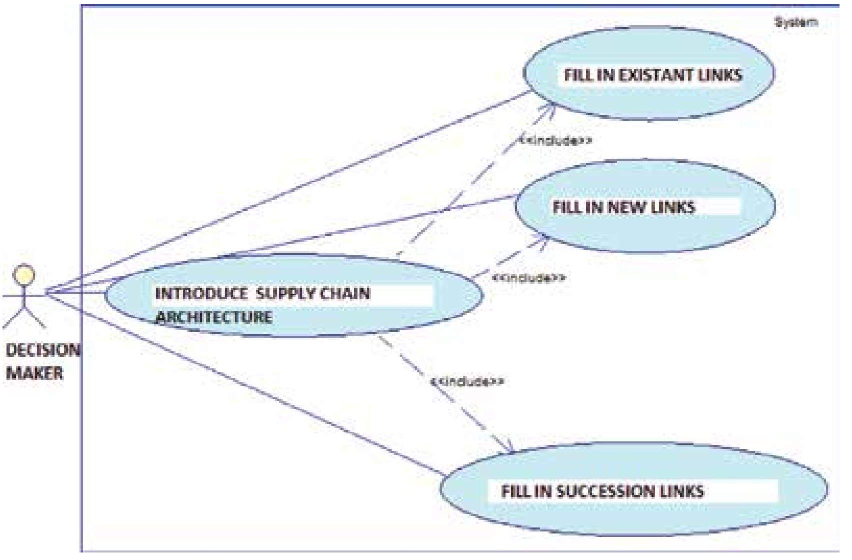

Figure 5. Use case diagram-Supply chain structure modeling.

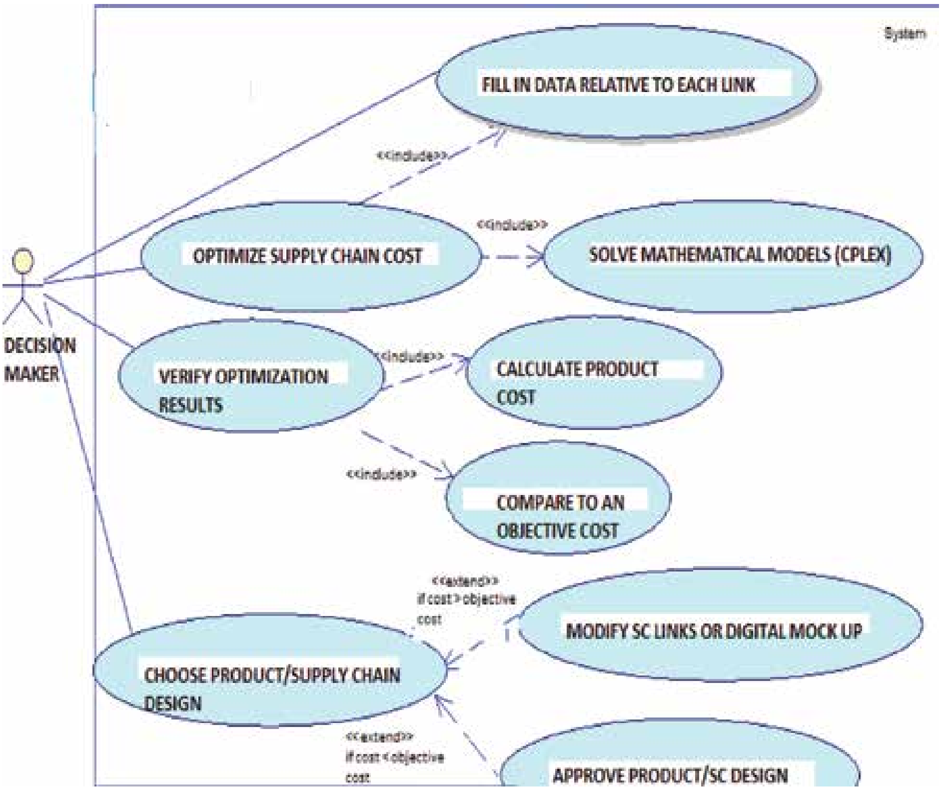

Figure 6. Use case diagram—Supply chain optimization.

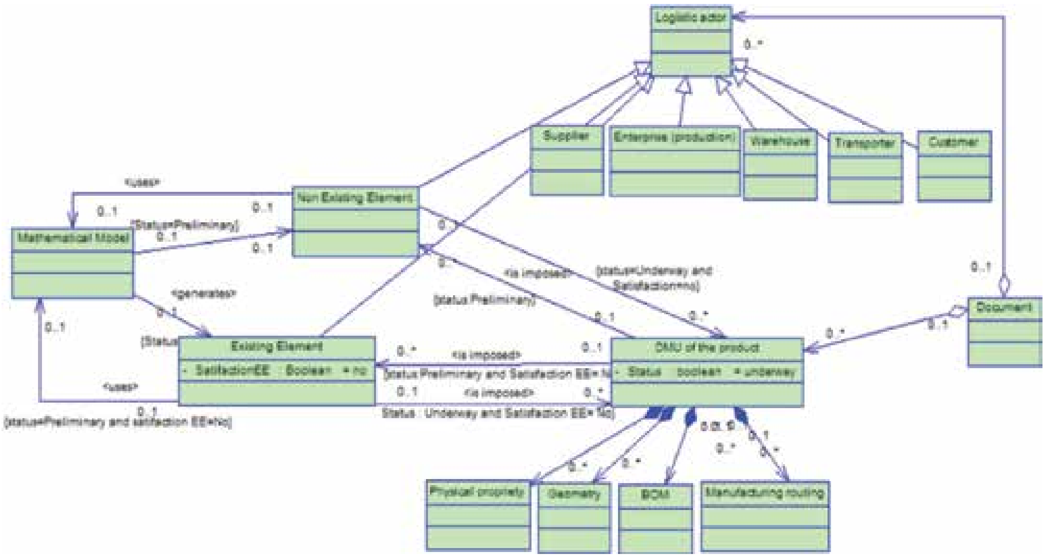

Figure 7. UML class diagram modeling the proposed methodology.

6. Conclusion

The competitiveness of a product on the market no longer depends on the company that assembles or sells it, but to all companies involved in the manufacturing process of this product and thus its entire supply chain. Therefore, the complex management of supply chains has increased the need for information exchange, sharing, and archiving.

Our work contributes to the field of integrated engineering, specifically the integrated logistics in the early stages of the product life cycle using PLM. Concretely, PLM enables a supply chain to become much more competitive by an effective collaboration among customers, developers, suppliers, and manufacturers at various lifecycle stages of a product.

In this chapter, we proposed a framework combining PLM and mathematical models to design the product and its related supply chain.

In our work, we defend the idea that the structure of the supply chain must be defined at the level of the product design that is to say at the level of the digital mockup. We then proposed a methodology based on the PLM approach for product design and its optimized supply chain.

Our approach takes into consideration, as a first step, the supply chain elements that already exist; their constraints must be integrated into the digital mockup. In a second step, designing new links must satisfy the digital mockup and the existing logistics network.

This approach combining PLM and mathematical models is based on three aspects:

- Organizational through the integration of the constraints of all the supply chain partners, responsible for main stages of the product life cycle.

- Technological by bringing together all the actors around the digital mockup; it structures the supply chain design.
- Mathematical by optimizing the costs of the different supply chain partners.

In our future work, we will implement the proposed methodology in two types of industries with different specifications: the agro-food packaging industry and the automotive industry.

Author details

Imane Bouhaddou

Address all correspondence to: b_imane@yahoo.fr

National High School of Arts and Crafts, Meknes, Morocco

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Recycling of Polymeric Composite Materials

Emilia Sabău

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Abstract

This chapter treats studies about the methods and technologies used to recycle the polymeric composite materials and develop new recipes using waste of polymer composite materials resulted from recycling. Composite materials obtained from recycling are presented, with a complete recovery of waste glass fibers. Also, the mechanical properties for new structures of polymeric composite materials, containing additional materials were presented. These were obtained from the recycling of composite waste. A morphology analysis of fracture area of composites samples was done. At present, the polymeric composite materials present a great scientific and technical interest, which justify both the development of research in this field, and the expansion of production of such materials. The author treats aspects regarding a current problem due to the large number of polymeric composite materials waste, and reduced of environmental impact. This field is representing one of the top viable research directions.

Keywords: waste, composite materials, glass fibers, polymer matrix, recycled materials

1. Introduction

In the last decades have revealed significant changes in the world in terms of the use of materials in various fields, mutations complained so special requirements of peak areas and increasingly diversified requirements related to the production of consumer goods and not least all environmental requirements.

Composite materials are considered engineering materials that can replace non-ferrous or ferrous materials. Polymer composite materials have a large applicability in a different industries such as electrical engineering, electronics, building and civil engineering, rail, road and marine, aerospace technique and aeronautical, etc. [1–8].

Composite materials consist of reinforcement material (glass fiber, carbon fiber, Kevlar, etc.) and a matrix (polyester resin, epoxy resin, and so on). Fiber glass is the most used reinforcing materials. They have many characteristics: high tensile strength, high chemical resistance, low cost. To obtain low price or to give high properties to a composite material we can include in a structure auxiliary materials, like: coupling agents, catalysts, pigments, accelerators and so on [9].

The storage of waste composite materials and the recovery of these, it's an important problem that we have nowadays. In **Figure 1**, it can be seen composite parts out of use and composite waste resulted from different production processes that occupy considerable spaces for storage. In time the accumulation of such materials can create serious problems to the manufacturing companies.

Because the interest to find solutions for recovering or recycling is very low, the accumulation in time of composite materials waste is very significant. We can obtain a material rich in glass fiber by grinding the composite materials waste. Thus, it's obtaining a very valuable

a.

b.

Figure 1. Composite materials waste stored.

reinforcement that can be embedded in other materials or can be used for obtaining reinforced composite materials. A solution for recycling such composite materials has been to grind these materials, **Figure 2** and create new composite products.

The recovery and recycling of polymeric composite materials has experienced an important concern in the last years. Researches dedicated to technologies for recycling composite materials were initiated and carried out by different authors, [10–13].

Mixtures of concrete with sand and fiberglass waste are known [14–16]. Waste composites can be used for concrete reinforcement or for a variety of construction materials. However, these materials from the known technical solutions point of view have higher density, lower mechanical properties, and the external factors like: UV radiation, moisture, sunlight, influence the degradation of these.

A chemical recycling of glass fiber reinforced epoxy resin has been proposed by Dang et al. [17]. PET reinforced with glass fiber was recycled by Giraldi et al. [18], while Bartl et al. [19] study the fibers recycling obtained from tires. Vilaseca et al. [20] treat in their research recycled Kraft fibers (recycled softwood fibers) that coming from old sacs, used as reinforcement for the preparation of polypropylene composites. Composite materials obtained from wood fibers were analyzed by Nemes et al. [21] and Augier et al. [22].

Hugo et al. [23] were investigated recycled polymers with a range of different fillers, and developed applications that use waste thermoplastic polymer.

In order to make the ornamental plates used in the field of construction, a number of manufacturing processes are known which use sand mixtures with different binders: plaster, whitewash or cement [24, 25]. The obtained material as a dry mix or mortar is poured and pressed into a mold. After reinforcement of the material, the plate is extracted from the mold, after which time is left for stabilization, and then it can be used.

Figure 2. Ground glass fiber.

For the same purpose, for the production of alternative materials it is known the manufacturing process of reinforced mortars used in construction [26, 27]. These mortars include besides sand, whitewash, cement, gypsum and various reinforcement materials, such as: hemp fiber, glass fiber, etc.

The disadvantages of these processes are the high time of plates obtaining and their reduced mechanical characteristics. Other disadvantages of the plates obtained by these processes are the high density of the material and the degradation in time under the influence of external factors: humidity, sun, UV radiation.

Reinforced materials and manufacturing procedures have a significant influence on the quality, productivity and competitiveness of composite structures. The interface between matrix-reinforced materials plays an essential part in the mechanical behavior and fabrication of composite materials.

2. Recycling of composite materials

The recycling of materials organic macromolecular surgery is more complicated than with traditional materials (glass, paper, metal), because there is an impressive variety of polymers, which in most cases are not compatible with each other, in the event of a global recycling [28–30].

For the recycling of polymeric materials there are several solutions:

- The separation of the constituents of mixtures in order to recycling of each individual component;
- The direct transformation of the mixture without prior sorting, in order to reduce the volume of waste.

From the view point of recycling, waste can be classified as:

- Manufacturing waste (10% of total waste) mainly formed of a single material. Because they are not contaminated (or less purified) with other materials, recycling is easier. Typically, these wastes are reintroduced into production lines.
- Waste easily separable. They consist of 1–2 or more polymers (mix macroscopic scale) otherwise contaminated materials (fillers). These materials are, at least theoretically separable.
- Microscopic mixtures or intimately connected (soldered, interpenetration). This is the case most difficult to treat because the separation of constituents is difficult or even impossible, requiring complicated operations. In this category fits very well with organic matrix composites. The most representative example is the waste from the automotive industry. In this case, the blend will find materials (resins) thermoplastic, polymer mix, fibers, fillers and multilayer composite materials.
- Materials of the recycling, currently applies in particular to the first two categories mentioned.

The recycling after separation of mixtures is a much more interesting because you have to drive theoretically product with performance very close to the base polymeric materials. In practice, the properties of recycled materials approaching initial properties of the base material, unless methods are very effective waste sorting and waste have undergone significant degradation during operation.

Sorting of waste is done according to the basic polymeric material. The sequence of operations mainly comprises the following steps:

Shredding. At this stage, the materials must be recovered shrinks size to be easily transported and handled.

Separation of metals is well-established methods, obviating the mixture all existing metal fragments (e.g. electromagnetic methods).

- Shredding and/or spraying. This stage is complementary to the first mentioned. At this stage takes place and the washing waste. Choppers additional step is required for further processing easier.
- Washing and drying is intended to remove all impurities. In general washing is done with water and detergent, but depending on the nature of impurities at this stage can put complex problems. Flushing is required followed by spin drying to remove water.
- Separation using air or hydro cyclones and disposal are conventional methods for separating materials based on the difference in density. The process stream is brought into contact with a stream of air (water) in a cyclone. With these separation methods do not obtain high degrees of purity. Moreover, this mineral phase (mineral fillers) often change the apparent density of the polymer, making it difficult to separate.

By materializing the proposed project creates prerequisites for achieving scientific and technological results, competitive at European level in order to increase the visibility of Romanian research, especially to subsequently transfer the results in socio-economic practice.

The resolving of proposed assignment will lead to the development of science-based knowledge of the manufacturing processes of parts of polymeric composite materials reinforced with biodegradable waste. The aim is to achieve a topic fundamental research, advanced to develop methods and technologies for recycling polymer composite materials and develop new recipes using biodegradable waste. It thus aims to improve the quality, productivity and competitiveness of industrial products. This is possible by using a multidisciplinary approach to research that brings together knowledge of chemistry, mathematics, physics, rheology and technological engineering.

3. Proposed new composite material and manufacturing method for ornamental synthetic plates

Both composite materials and waste composite materials resulting from production processes occupy important storage areas with an impact on the environment.

It shows the utilization of the glass fiber waste obtained by grinding the waste resulting from the manufacturing technological process of composite materials or removing them from their use and incorporating them in a product with applications in the field of industrial constructions, offering superior mechanical characteristics to the existing similar products.

3.1. The matrix

The mold, for obtaining the ornamental synthetic plates, is made of two separate modules, one of silicone rubber and one of fiber reinforced composite material. In **Figure 3** are presented the steps of mold forming.

Achieving the active part of the silicone rubber mold eliminates the need for additional separation planes, and the mold stiffness is ensured by reinforcing it with a fiber reinforced composite material. The use of matrix mold from the silicone elastomer eliminates additional separation planes reducing the cost of the mold.

The manufacturing process of the matrix, involves the following phases:

- arranging the stones, **Figure 3(a)**,
- filling the joints with gypsum,
- forming the outer frame,
- applying the demulation layer, PVA (Polyvinyl alcohol),
- preparation and application of the silicone rubber, **Figure 3(b)**,
- realizing the composite structural element for the silicone mold, fiber glass/polyester matrix, **Figure 3(c)**,
- demulation of the mold from fiber reinforced composite material, **Figure 3(d)**,
- demulation of the mold from silicone rubber, **Figure 3(e)**,
- trimming edges, **Figure 3(f)**.

3.2. The material

The process of ornamental synthetic plates manufacturing consists in a mixing, in a recipient, of calcium carbonate with the polyester matrix 5 minutes, casting these materials into a modular mold made from silicone and reinforced by a fiber-reinforced composite material and maintaining at room temperature for 20 minutes until the matrix gel point has been reached, mixing in another recipient for 10 minutes of waste glass fiber ground with a polyester matrix and 0–0.3 mm sand, and molding it in the die over the initial molded material, holding molds in the die approx. 2 hours at 60°C, resulting an ornamental plate that is released from the mold after composite material polymerization. The material together with the unpolymerised matrix is deposited in a modular mold.

The sand was used as a low-cost reinforcement material in the form of particles with transparent aspect. The morphological analysis of the sand is shown in **Figure 4**.

Figure 3. Steps of mold forming.

The manufacturing process of synthetic decorative plates involves the following phases:

a. preparing the mold and applying the first layer release agent,

b. preparing the first mixture consisting of 60% polyester matrix and 40% Calcium Carbonate $CaCO_3$, mixed approx. 5 minutes in a recipient,

c. casting the first mixture so that it will cover more than 1–3 mm the height of the mold asperities and the maintenance until reaching the gel point, at room temperature,

d. preparing the consolidation mixture consisting of 30% sand of the 0–0.3 mm sort range, 30% grinded glass fiber waste and 40% polyester matrix and mixing it for 20 minutes,

e. casting the consolidation mixture over the first mixture until the mold filling and leveling the upper part,

f. transferring the mold with the composite mixture in a polymerization heat and maintaining in the mold at a temperature of 60°C, about 2 hours, until the composite material polymerization,

g. mold release and obtaining the ornamental synthetic plates.

The composite material consists in obtaining a synthetic material composed of two component mixtures, **Figure 5**:

- the first mixture, which forms the surface layer that copy the mold and render the appearance of the synthetic plate, **Figure 6**, consist of 60% polyester matrix and 40% Calcium Carbonate $CaCO_3$, mixed approx. 5 minutes, casted and maintained until the gel point was reached;
- the second mixture, of consolidation, consist of 40% polyester matrix, 30% sand of the 0–0.3 mm sort range, 30% grinded glass fiber waste, casted over the first mixture and maintaining in the mold until the polymerization, resulting a synthetic composite material reinforced with glass fiber having superior mechanical properties to similar materials used in construction.

The percentages mentioned above represent the percentage of the total volume of the constituent materials.

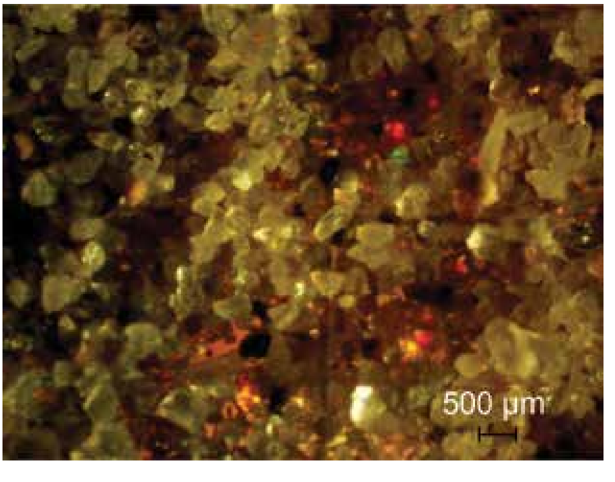

Figure 4. Sand grains.

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Figure 5. The synthetic material consisting of two component mixtures.

The obtained material is a compact material with resistance at external agents, the process being easy to achieve. The composite material provides superior mechanical characteristics to traditional materials and can be used in other applications in the construction field such as reinforcing structures.

The following advantages are obtained:

- composite material waste utilization, thus solving the significant problem of glass fiber waste;
- enlarge the range of materials used in construction;
- making a composite material having superior mechanical characteristics and low density with respect to traditional materials;

- getting some plates with good look, imitating the natural stone, which can be colored in large quantity in the production process and can be easily mounted on facades and buildings;
- the technological simplicity of the process does not require substantial investment;
- the use of matrix mold from the silicone elastomer eliminates additional separation planes reducing the cost of the mold;
- increasing the mechanical characteristics when using these materials at low temperatures.

3.3. Mechanical tests

For mechanical tests, from the obtained material was done cubic specimens with 50 × 50 × 50 mm dimensions, according to EN 12320-3 standard.

The obtaining process of the composite plates that include in the structure glass fiber waste was hand lay-up. The mechanical properties of composite plates were determined to perform the experimental test at compressive load.

Figure 6. The ornamental synthetic plate.

No.	Force [KN]	Average force [KN]	Average compressive breaking strength [MPa]	Density [Kg/m^3]
1.	185.8			
2.	191.2			
3.	193.2	189.96	78.27	1380
4.	187.3			
5.	192.3			

Table 1. Compressive tests results.

Table 1 shows data following the compressive stress of cubic specimens, the constituent composite material remains bonded through filaments of reinforcement material.

The composite plates provide higher mechanical properties, lower costs and reduce waste materials in the environment.

The experimental data shows that the new materials have good mechanical properties and they can be successfully used in the dimensioning and verification process of composite structures resistance.

3.4. Microscopy study

The microstructure of fracture samples from waste glass fibers/sand/polyester matrix composites was analyzed using a metallographic microscope type Optika XDS-3 MET [31, 32].

The sand grains contain in the structure over 90% silica (SiO_2). The glass fibers are made from silica sand, which melts at 1720°C.

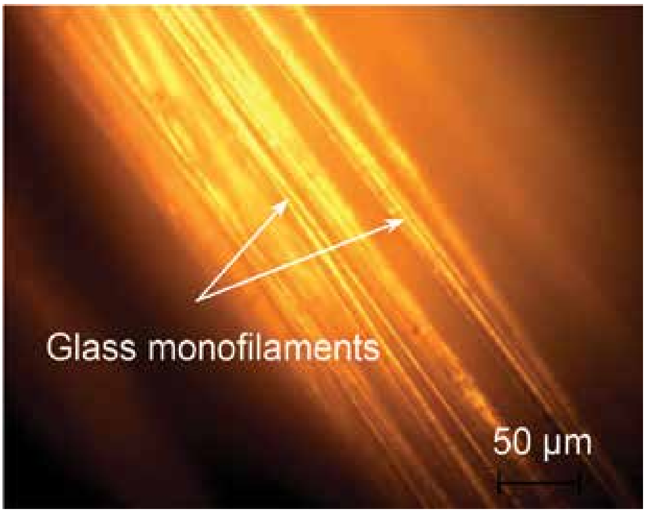

Figure 7. Non-impregnated glass fiber monofilaments.

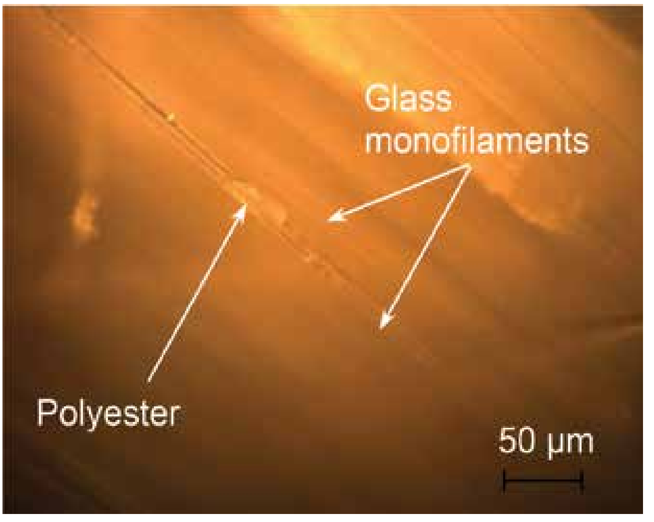

Figure 8. Impregnated glass fiber monofilaments with resin.

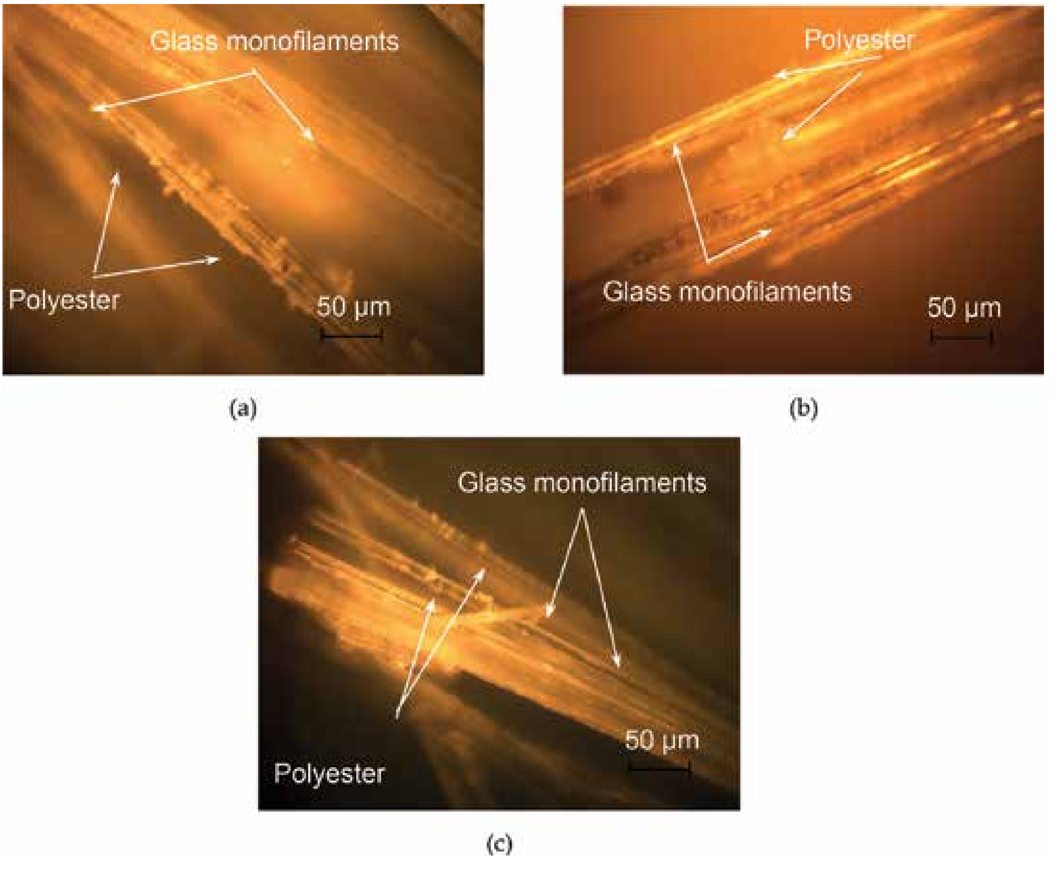

Figure 9. Waste glass fiber monofilaments impregnated with resin.

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The monofilaments of non-impregnated glass fiber have a smooth and glossy surface, specific to the glass. These were analyzed using the optical microscopy, **Figure 7**. To have a good adhesion at the interface between matrix and fibers, the surface of glass fibers is treated with silane. In **Figure 8** it's show the impregnated glass fiber monofilaments with resin.

Figure 9 shows the adhesion between matrix and glass fiber monofilaments. **Figure 10** illustrates that sand grains and glass fiber monofilaments are well impregnated with resin according to the morphological analysis of the fracture area. It can be observed a good compatibility between resin, filaments and sand, and a good impregnation of the matrix.

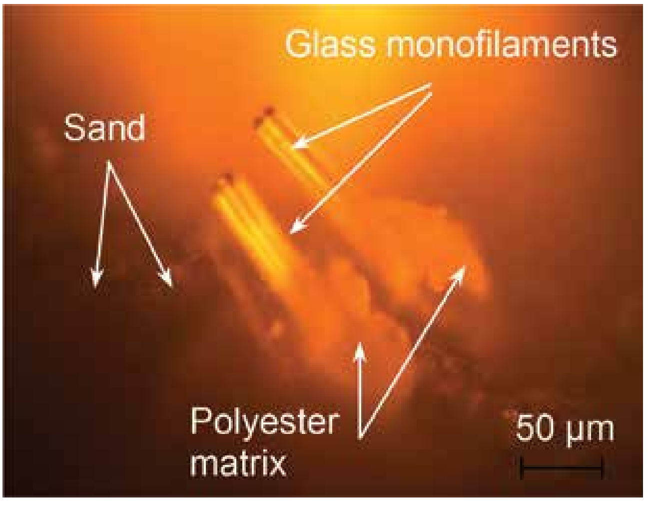

Figure 10. The fracture zone of waste fiber glass/sand/polyester resin plate.

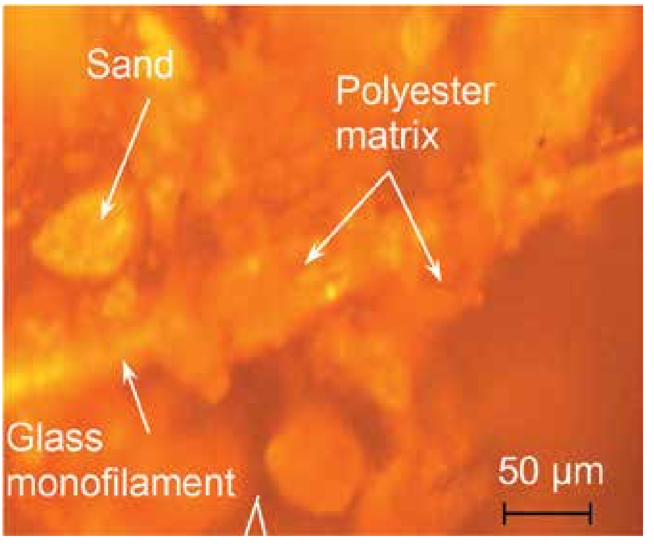

Figure 11. Sand and glass monofilaments in polyester resin.

According to the **Figure 11**, it can be observe the achieved connection between polyester matrix, glass fibers and sand, because of the particles of sand and polyester resin that were well glued on the glass monofilaments. Thus, a composite material with low density and high mechanical properties has obtained. These types of materials allow one reuse of glass fiber waste. Using these types of materials at low temperatures increases their mechanical characteristics.

4. Energy dispersive x-ray analysis

With the help of the energy dispersive x-ray spectroscopy (EDX) was performed the elemental analysis of the polyester resin and waste fiber glass. The weight fraction ratio is composed on the total weight of the chemical substances analyzed. The predominance of silicon and aluminum can be observed in the **Figure 12**, after the elemental EDX analysis was done of the waste glass fiber [32]. Also, small amounts of carbon, oxygen, sodium, magnesium and calcium are detected. The obtained data are expressed in two ways, both atomic percent (At.%) and weight percent (Wt.%). The atomic and the weight percentages of the fiber glass elements are: C with 30.96At.%, 17.67Wt.%; O with 24.12At.%, 18.34Wt.%; Na with 0.34At.%, 0.37Wt.%; Mg with 0.38At.%, 0.43Wt.%; Al with 14.43At.%, 18.50Wt.%; Si with 21.12At.%, 28.19Wt% and

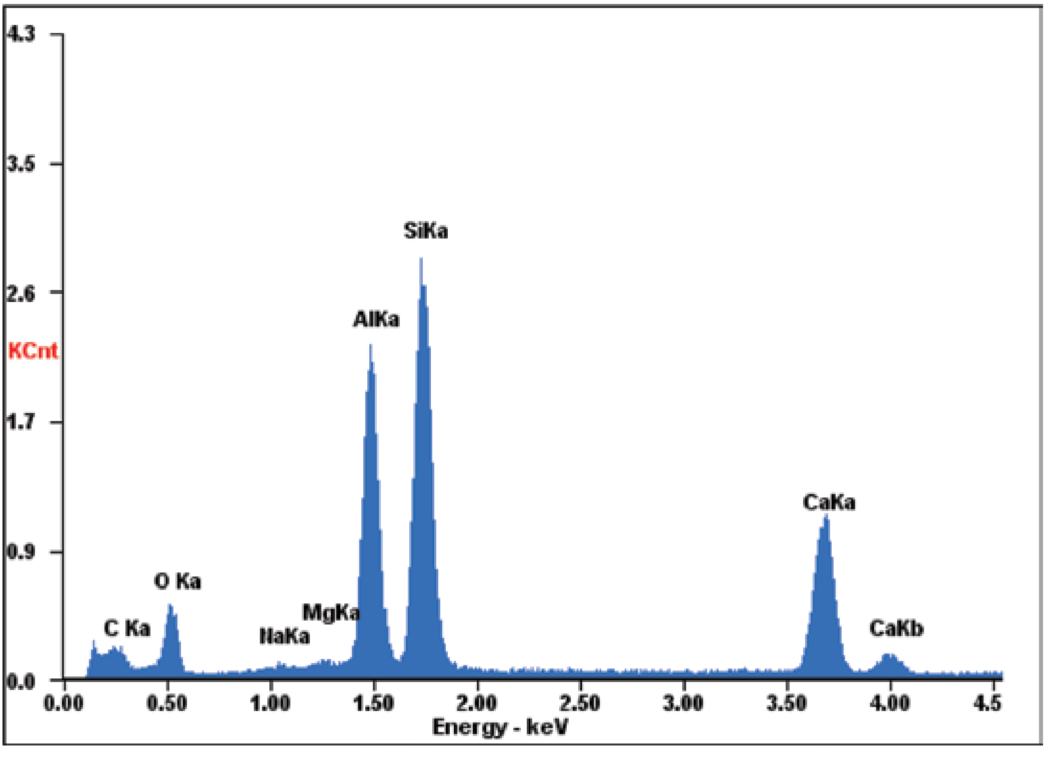

Figure 12. EDX analysis of the chemical constituents from the glass fiber.

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Element	At.%	Wt.%
Si	21.12	28.19
Al	14.43	18.50
Ca	08.66	16.50
O	24.12	18.34
C	30.96	17.67
Mg	00.38	00.43
Na	00.34	00.37

Table 2. EDX analysis of the glass fiber.

Ca with 8.66At.%, 16.50Wt.%. In **Table 2** are presented the elements on the surface of a waste glass fiber.

The EDX analysis of the matrix polymer is presented in **Figure 13**, [32]. The predominance of carbon, silicon and oxygen is obviously in this case study. Also, small amount of sodium, aluminum and calcium are detected. The atomic and the weight percentages of the polyester matrix

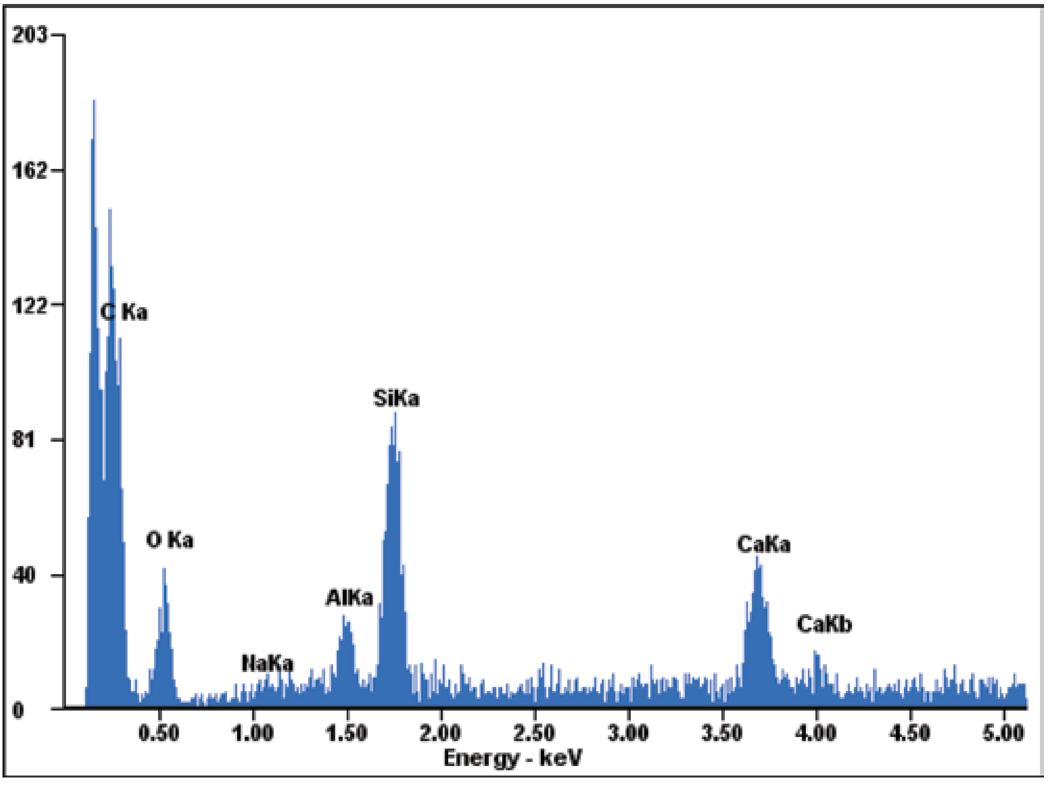

Figure 13. EDX analysis of the matrix polymer.

Element	At.%	Wt.%
C	74.80	62.18
Si	04.78	9.30
O	15.97	17.69
Ca	02.87	7.98
Al	01.28	2.39
Na	00.29	0.47

Table 3. EDX analysis of the matrix.

elements are: C with 74.80At.%, 62.18Wt.%; O with 15.97At.%, 17.69Wt.%; Na with 0.29At.%, 0.47Wt.%; Al with 1.28At.%, 2.39Wt.%; Si with 4.78At.%, 9.30Wt.% and Ca with 2.87At.%, 7.98Wt.%.

In the table above, **Table 3**, are presented the elemental quantitative analyses that give us the polyester matrix elements on the surface.

5. Conclusions

The storage of waste composite materials and the recovery of these, it's an important problem that we have nowadays. Composite parts out of use and composite waste resulted from different production processes occupy considerable spaces for storage. The manufacturing companies can be affected by serious problems, because of the accumulation in time of these types of materials.

A solution for recycling these composite materials has been to grind these materials and create new composite products.

A new composite material obtained from recovered materials, with a complete recovery of glass fibers waste is described in this study.

The composite material for obtaining the ornamental synthetic plates consist of a mixture that forms the surface layer, that copy the mold and render the appearance of the synthetic plate, consist of 60% polyester matrix and 40% Calcium Carbonate $CaCO_3$ and a consolidation mixture consist of 40% polyester matrix, 30% sand of the 0–0.3 mm sort range, 30% grinded glass fiber waste, casted over the first mixture and maintaining in the mold until the polymerization.

The experimental properties obtained indicate a very good mechanical behavior of the new composite materials. The compressive tests indicate a high value, superior of traditional materials, like concrete.

The fracture area of the samples from glass fibers waste/polyester resin/sand composites was microscopically analyzed. A good compatibility between resin, filaments and sand, and a good impregnation of the matrix was obtained.

The new composite material contained grinded glass fiber waste, polyester matrix and sand all mixed together. After polymerization of the resin we obtain a composite material with superior mechanical properties. This material can be used in different applications, like: strengthening composite parts (ornamental garden stones, ornamental composites plates, garden furniture, additive materials and so on), polyester reinforced concrete.

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Author details

Emilia Sabău

Address all correspondence to: emilia.sabau@tcm.utcluj.ro

Technical University of Cluj-Napoca, Romania

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The aim of this book is to present the terminology, applications, trends, and developments in Product Lifecycle Management (PLM). This book has a total of seven chapters that treat the fundamental and future terminology used in PLM, aspects regarding the design, customization, and development of products, products testing, supply chain optimization, and recycling of the products made of special materials.

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