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DIGITAL TWINS: DEFINITION, APPLICATION OPTIONS IN THE PRODUCT LIFE CYCLE AND MARKETING

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ABSTRACT

Germany is in the digital transformation process of the economy and society. Digital transformation influences not only production and marketing, but also the consumption and use of goods. The development and use of digital twins accelerate the digital transformation process and increase the competitiveness of the German economy. So far, the focus of research has been on the use of digital twins in the production of industrial goods. This article analyzes the use of digital twins in consumer goods marketing. For this purpose, the concept of digital twins is explained, and its use is presented over the entire life cycle of durable consumer goods. Subsequently, the possibilities of use of the digital twin in marketing will be presented and an outlook on further research fields will be given.

Index Terms – digital twin, product lifecycle, customers' satisfaction, marketing, digital technologies.

1. INTRODUCTION

Digitalization is changing not only the production of industrial goods and services but also the production and consumption of consumer goods and thus our entire living environment. The technology is used across many industries to provide accurate virtual representations of objects and simulations of operational processes [1]. In today's digital age, where business agility is not only a desire but a necessity, digital twins (DTs) are expanding, redefining the future of enterprise operations [2]. The product development, production process, and marketing of innovative products are no longer possible without DTs today. A digital twin (DT) is a digital model of a real object, which is constantly developed further by data taken from the object [3, p. 3]. DTs support companies from the stage of product development through the entire product lifecycle. They open up cost and time saving potential for companies, enable the development of product-service systems as well as individualized products, and increase customer satisfaction.
Since its very beginning, DTs have continued to evolve quickly and gain traction as an important problem-solving tool in life sciences driven by advances in artificial intelligence (AI), cloud computing, Internet of Things (IoT), and simulation by blending the relative strengths of these component technologies [4]. According to Gartner's research [5], 75% of organizations implementing it already use DTs or plan to within a year. Global Market Insight (GMI) in its report, Digital Twin market size by application, published in April 2023, highlighted that DT

market size is valued at USD 8 billion in 2022 and projected to witness over 25% compound annual growth rate (CAGR) from 2023 to 2032 when this market will be worth approximately 90 billion USD [6]. Gartner [7] predicts in 2027, over 40% of large companies worldwide will be using DTs in their projects to increase revenue.

However, despite their promising potential, DTs are not yet being used extensively [8, p. 3], [9, p. 97]. The reason is that the concept of DTs raises questions regarding implementation because of a lack of experience and standards in companies. There are many various definitions for DTs in the literature. Regarding marketing, the restrained use of DTs leads to companies squandering opportunities in sales markets and thus damaging their competitiveness.

Another challenge faced by DT researchers is the fact that this concept is mostly applied in production and somewhat less applied in product life cycle management. Also, great importance is attached to this concept and great expectations are attached to it that it will achieve wide application in almost all areas.

This paper aims to answer the following research questions: What is a DT and how does a DT work? How can DTs be used in the product lifecycle management of consumer goods? What options are there for using them in the marketing of consumer goods?

To answer the questions raised, the paper structure is as follows. In the first part, the term DT will be defined, as well as the review of its use in the literature. Then, the concept of the DT will be presented. After that, the theoretical constructs of consumer goods and product life cycle are defined and explained. In the second part of the article, we show how the DT can be used in the phases of the product life cycle of consumer goods. In the last part of the paper, we will highlight the potential uses of DTs in the marketing of consumer goods.

2. DEFINITION OF DIGITAL TWINS AND PLACEMENT IN THE LITERATURE

The concept of DTs has become widespread today as rapidly expanding digital technologies have created the conditions for its development and implementation. Although the concept is regarded as very young, the initial idea of this concept was generated decades ago. The idea of DT occurred in NASA's Apollo project in 1969 [10], [11]. Some authors [12], [13] claim that the idea of twins was first time proposed in 1980s by NASA for the purpose of monitoring the status of an aircraft in space from Earth.

The origin of DT concept is credited to Michael Grieves and its work with John Vickers of NASA. The concept of a virtual, digital equivalent to a physical product or the DT was introduced in 2003 by Grieves in the University of Michigan Executive Course on Product Lifecycle Management (PLM) [14, p. 1]. For creator of this concept, DT is promising because expect many shortcomings to be detected and corrected, as well as to predict possible problems in the recent future, which are related to the historical data that DT collects and uses in its work [15]. To meet mentioned and many other expectations, concept of DT must include three main components: physical unit (product), virtual unit (virtual representation of its product), and bi-directional data that enables connection and communication between these two units.

According to Glaessgen and Stragel [16, p. 7] a DT is an integrated multyphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin.

In the literature review, there are many authors that build their definitions of DT concept related to Grieve's initial idea. Some authors [17]–[19] define a DT as a virtual model and a full representation of the system used to understand performance metrics, improve processes and effectively improve value-added activities. Guo et al. [20] defines DT as a digital equivalent of the physical systems based on a simulation that deals with design systems and optimizes them for improved efficiency. Stark et al. highlight that DT is the digital representation of a unique asset (product, machine, service, product service system or other intangible asset), that compromises its properties, condition and behavior by means of models, information, and data [21, p. 169], while Kannan and Arunachalam [22] explain it as assets which can communicate, cooperate and coordinate the manufacturing process for an improved productivity and efficiency through knowledge sharing. For Söderberg et al. [23] concept of DT refers to using a digital copy of the physical system to perform real-time optimization. The shortest and at the same time the brief definition of DT proposed Qi and Tao [24] in their work. According to them, the concept DT presents virtual models of physical objects that is created in a digital way to simulate their behavior in real-word environment. Xu et al. define DT based on its role – simulating, recording and improving the production process from design to retirement, including the content of virtual space, physical space and the interaction between them. In the same paper, they highlight that the properties of DTs are hyper realism, computability, controllability, and predictability [25, p. 19990].

Certain groups of authors [26]–[28] describe DT through its role of simulating the manufacturing environment based on the collected data which assists the owners to make right decisions and the final impact results in better effectiveness, precision and economies of scale. The strength of DT relies in ability to control the production process in response to achieve high level of agility and accuracy on the market [19].

Based on the definitions listed, the following general definition for DTs is derived: A DT is a software unit that depicts a material object, system, service or other intangible asset with respect to selected properties, states and behavior in a highly accurate and current virtual manner [29, p. 1]. The high accuracy and up-to-dateness is ensured by information collection, information exchange and information processing in real time, optionally along the entire life cycle. The DT is closely related to classical modeling and can be used for various simulations.

Besides different definitions, there are also different areas of application for DTs in the literature. Tao et al. [30, p. 3563 f.] see DTs as an opportunity to use big data in product lifecycle management. They discuss the use of DTs in product design, product manufacturing, and after-sales service. Most publications deal with the use of DTs in the prognostics and health management of technical systems. Likewise, the use in production is approached more often while less frequently in the design of products [31, p. 2409].

In recent years, most research has focused on the use of DTs in the production of industrial goods [32, p. 187–194], [33, p. 44], [34, p. 3]. To date, there have been few research contributions on the use of DTs across the entire product lifecycle for consumer goods. So far, very few articles deal with the use of DTs in all stages of the product lifecycle [30], [35]–[38]. Often, the beginning and the end of the product life cycle don’t deal with this. The main focus is on the implementation and use stages of the product. Most of the articles have been published in journals dealing with engineering [39]–[41], manufacturing [35], [38], and industrial engineering. They primarily deal with the applications of the DT in the manufacturing of products, especially in combination with industry 4.0 and smart factory. To date, several papers describe the application of DT in different business areas [42]–[48] and the use of DT has increasing trend.

3. CONCEPT OF DIGITAL TWIN

In the literature review, there are many points of view on how DTs work and what they consist of. As mentioned before, to exist a DT should be composed of at least three components: a physical component (entity as product, service), a virtual component (an entity that presents a virtual replica of a physical entity), and the third component relates to a bidirectional data that connect physical and virtual component.

DT structure is based on three dimensions: physical parts, virtual parts, and connection parts [14], [24]. There are authors that present the structure of DT based on the four components [49],

while some authors [31] propose a structure composed of five dimensions: physical part, virtual part, connection, data, and service. In this paper, the three-dimensional model developed by Jones et al. [15] will be presented, discussed, and analyzed.
As mentioned before, the DT is a software unit that connects the physical and virtual parts of any product. Therefore, the connection and communication between these two units is necessary. This process of communication is called mirroring or twinning between physical and virtual spaces. The simplified scheme of this process is proposed by Jones et al. [15]. Based on the literature research, we propose some adjustments to the data and information flow between the physical part and the virtual part, as presented in Figure 1.

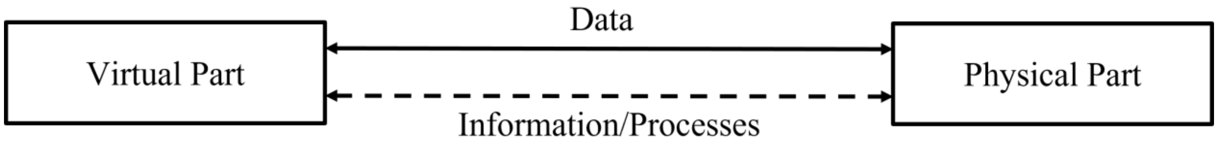

Figure 1. Simplified structure of DT

In their work, Jones et al. [15] also presented the detailed inter-relationship process of twinning, as presented in Figure 2. To explain its functionality, we need to identify its components and associated elements. According to Jones et al. [15, pp. 39-43] the elements of the DT concept are presented in Table 1.

Table 1. Digital twin elements and its clarification

Digital twin elements	**Clarification of the element**
Physical entity/twin	A man-made entity that exists in the real world (product, service, system, model, etc. that is characterized as *smart*).
Virtual entity/twin	Presents the virtual replica of a physical entity generated by a computer.
Physical environment	Presents the real-world space in which a physical entity is set. It includes all parameters that may affect a physical entity.
Virtual environment	Is a mirror of the physical environment and exists within the digital domain.
State	Presents the actual status of both entities, physical and virtual, as well as the conditions of the measured parameters.
Parameters	Present the characteristics related to the entity, and the original set of data that flows between the two entities.
Fidelity	Includes the count of parameters, their precision, and the degree of abstraction that is transmitted between the digital and physical twin/environment.
Metrology	Measuring the current state of the physical/virtual entity.
Realization	Computing the delta (the difference between the current and previous state) and sending the delta determined in the metrology stage from the physical/virtual to the virtual/physical entity to accomplish synchronization between them.
Physical-to-virtual connection	Presents the data transfer of physical entity to the virtual environment.
Virtual-to-physical connection	Presents the data transfer from a virtual entity to the physical environment.

Twinning	Present the data transfer between physical and virtual environment and vice versa.
Twinning rate	Presents the frequency of data transfer, as well as the frequency of measuring, computing and sending computed delta between two states of physical and digital entity and environment and vice versa.
Physical processes	Refer to sending new, changed data from physical twin parameters to the virtual twin.
Virtual processes	Refer to the activities performed using the virtual entity within the virtual environment.
Twinning process	Consolidates all components into one entirety to create a synchronization between the physical and the virtual part of the twin.

Source: Adjusted according to [15, pp. 39-43]

Those elements presented in Table 1 jointly create a DT and enable its existence. The DT consists of two groups of entities and elements, the physical twin and the virtual twin, that are connected to be fully synchronized so that the physical twin represents the virtual twin and vice versa. The physical twin comprises the physical entity, physical environment, physical processes, physical metrology, and realization in the process of physical-virtual connection. The virtual twin comprises the virtual entity, virtual environment, virtual processes, virtual metrology, and realization in the process of virtual-physical connection.

The twinning process is what is presented in Figure 2. This process consolidates all elements presented in Table 1, into one entirety, to create a synchronization between the physical and the virtual part of the twin.

We will explain how DT works, using a physical entity state as a starting point. Physical entity (e.g., smart product) changes under the influence of physical processes. The physical entity state presents the status of the physical entity, as well as the physical environment. The state of the physical entity and the physical environment reflects on the virtual entity and virtual environment to achieve synchronization between them. This process of synchronization is based on physical-to-virtual connection, which consists of two phases: physical metrology and realization. In the first phase, physical metrology, the new state of the physical entity is determined by measuring values of different parameters that describe the current state of this entity. Physical metrology is based on auxiliary components such as sensors (RFID–Radio Frequency Identification, and similar), that collect various data on the current state of the physical environment. Measured values are sent to the virtual environment. Then, the change (delta) between the current physical entity state and the previous virtual entity state is computed and the virtual entity is updated, so both entities are the same. This presents the realization phase, the second phase, in the physical-to-virtual connection. This synchronization, the data transfer of physical parameters, is based on some kind of communication technologies such as Internet-of-Things (IoT), web-services, 5G (5th generation of cellular network), etc. The adjustment of the virtual entity to a physical entity presents the moment when the physical and virtual parts of the DT are mirrored.

As DT, the concept that we analyze here, is bi-directional, the data flow exists in the opposite direction, from the virtual environment to the physical environment. The virtual entity is affected by virtual processes, activities that take place in the virtual environment and are based on simulation, modeling, and optimization. The state of the virtual entity presents the optimal set of parameters for the physical entity or environment [15, p. 41] which is measured in the virtual metrology phase. The virtual environment exists within the digital domain and is a mirror of the physical environment. For its existence, the virtual environment relies on some digital technologies such as database, clouds, and application programming interface (API), which enable it to co-exist parallel with the physical environment. The mentioned technologies store all the measured data obtained from the physical environment, process the data, and calculate the required (optimal) value based on it. This calculated value is now being sent to the physical entity/environment to become synchronized. By comparing the optimally calculated virtual entity value to the current physical state value in the realization phase, the delta between the new optimal virtual entity state and the current physical entity state is computed. Then, the change in the physical entity is done by some actuator. In this way, the process of virtual-to-physical connection, which consists of two phases, virtual metrology and realization, is achieved.

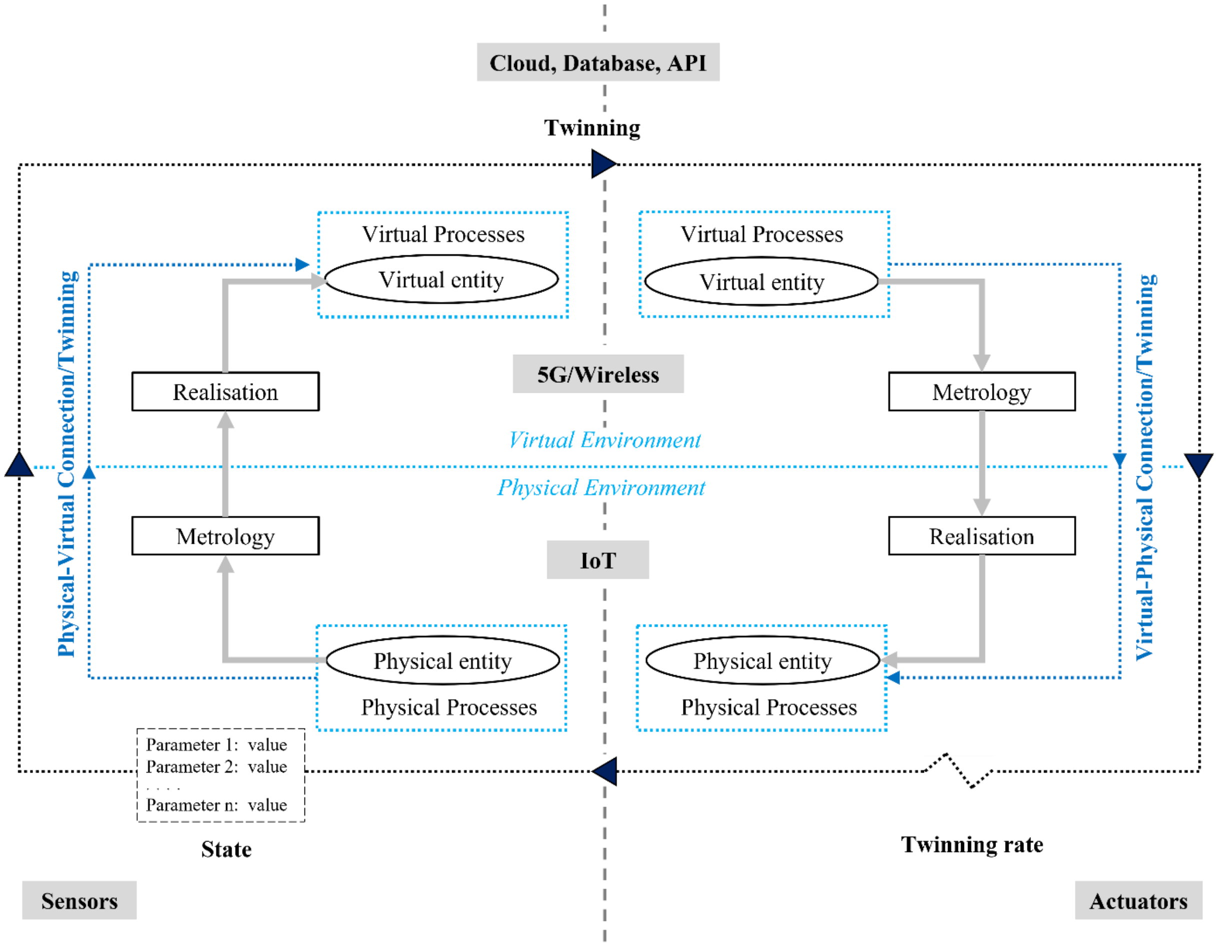

Figure 2. The physical-to-virtual and virtual-to-physical twinning process and essential technologies that enable it
Source: Adjusted according to [15, pp. 44-45]

When a new change in the physical entity and environment happens, the process starts all over again. The twinning rate represents the frequency of reconciliation to make both parts of the twin synchronized. This is how DT works. It presents the closed-loop connection between two crucial parts, the physical twin and virtual twin, that are constantly connected to each other, creating DTs.

4. DEFINITION OF CONSUMER GOODS AND PRODUCT LIFE CYCLE

Consumer goods are tangible commodities produced and subsequently purchased to satisfy the wants and perceived needs of consumers. Consumer goods can be distinguished from capital goods, such as plants, machine parts and raw materials. Consumer goods, such as food, are consumed directly, while consumer goods, such as vehicles, are used for consumption. Smart products are particularly relevant for the use of DTs, as smart product enables interaction with their environment and real-time data transfer over the product life cycle.

The authors place a smart product as an interface between customers and product manufacturers at the center of their analysis. Smart products have characteristics that enable, among other things, the localization and identification of the product [50, pp. 9-10]. The properties allow both the producer's external access and the monitoring of the activities of the smart product by the consumer. The aim of the consumer is to maximize the benefit through the use of the product. The aim of the producer is to optimize the state of the product and to analyze the generated usage data to maximize its yield.

According to Beverungen et al. [50, p. 12-14] the smart product serves as a boundary object. Both the consumer and the producer have the possibility to access the product via interfaces, but not to directly view the activities of the other party. The activities of the consumer are summarized under front-stage use. This includes the direct interaction of the consumer with the product. On the other hand, the influences from the physical environment on the product behavior are included. The data sent by the intelligent product allows product activities to be monitored in real time. Since the DT is able to autonomously control changes based on user behavior or user requirements, this function is all the more important. By connecting the product, the producer can retrieve real-time data externally and control and optimize the product condition based on the information obtained [51, p. 49]. The producer's activities are summarized under the term back-stage analytics. Retrieved data is monitored and malfunctions diagnosed. The data is aggregated, stored and analyzed.

Smart products have a life cycle in which they differ depending on the life cycle phase. A product life cycle describes the life path of a product. It shows the time development of a product on the market. It is assumed that each product goes through certain stages by law and has a certain lifespan. The life cycle is divided into the introduction, growth, maturity, saturation and decay phases [52, p. 45].

Eigner et al. [53, p. 348] divide the life cycle of smart products into the as-designed-, as-built- and as-maintained-phases. The as-designed-phase covers all the activities of product development up to the production release of a product. Lutz et al. [54, p. 423] classifies product planning and development, factory and process planning, as well as procurement into this phase. All activities in production up to the handover of the smart product to a customer are summarized in the as-built-phase. The tasks from factory operations and production, as well as sales and sales logistics, are assigned to this phase. The final phase of the use, disposal and recycling of a smart product is referred to as Eigner et al. [53, p. 348] as an as-maintained-phase. The as-maintained-phase contains all the five phases named by Bruhn [52, p. 45].

5. APPLICATION OF DIGITAL TWINS IN PRODUCT LIFE CYCLE MANAGEMENT

We have already presented the concept of how a DT works and what a product life cycle is. Per se, the offer of a DT does not represent any added value for a customer. Only using the DT for the optimization of a product, process or service a value is generated [55, p. 15]. The DT is used throughout the entire product life cycle. Now we are showing in which phases of the product life cycle and what the DT can be used in product life cycle management of smart products.

In the as-designed phase, in which ideas are won, selected and realized, DTs with their simulation functions can help to test and select product ideas and possible solutions [56, p. 9]. Furthermore, DTs can collect data on customer demand and customer, which can be used in the creation of new product ideas.

In this phase, prototypes can be created with the help of the DT, which can be tested in cost-effective simulations and then further developed [57, p. 95-96]. In this way, products can be developed faster and more efficiently [31, p. 2409]. In addition, DTs can support product development by sharing information via a cloud with their DTs using intelligently connected products used by users. The findings gained in this way can be incorporated into the development of future products [58, p. 9]. The idea of using information from the DTs of old products is also represented in the concept of Grieves and Vickers [57, p. 98].

In the as-built-phase, DTs can be created: of the product to be manufactured; of the machines involved in the production [59, p. 1130] and from production lines [60, pp. 258-260]. By creating a DT instance in parallel with the production process, all product specifications are also recorded digitally [57, p. 97]. Thus, for example, the production progress can be recorded. Many authors are working on the potential of DTs in production to make them more reliable, efficient and adaptable. For example, Tao and Zhang [49, p. 20420], who see in DTs of production facilities the opportunity to incorporate optimizations and insights from simulations taking place in the virtual world into real production. By Weyer et al. [61, p. 100] DTs can be used to predict errors, increase efficiency and monitor, optimize and adapt processes. The use of DTs in machines involved in production, for example, deals with Luo et al. [59, p. 1136], who see the use of DTs in, among other things, fault diagnosis and error prediction in computerized numerical control (CNC) milling machines. DTs can facilitate logistics processes in sales through real-time monitoring and other functions [43, p. 1324].

With the help of DTs of materials, new packaging solutions can be developed that meet today's requirements. Together with the information about the packaging, DTs of the shipped goods can support the automation of logistics processes. Information about the geometry taken from the DT can be used, for example, in automated packaging. DTs of logistics centers and warehouses can help optimize operations by using simulations and real-time monitoring. In addition, the information collected by the DTs can be used in the planning of new warehouses and logistics centers [62, pp. 22-24].

In the as-maintained-phase, DTs can be used to improve the use, configuration and maintenance of products. By developing analytical models of the use of consumer goods, DTs can make the use of products more efficient, for example, by reducing resource consumption. An important field of application of DTs and their simulation and monitoring functions is predictive maintenance [43, p. 1325]. For example, sensor data and results from simulations are used to estimate the remaining lifetime of product components, which in turn feeds into the decision on the next maintenance measure [63, p. 1069]. DTs also enable the reconfiguration and improvement of products already used by the user by continuously developing and providing software or hardware improvements [64, pp. 166 -167].

At the end of the as-maintained-phase, DTs can simplify the recycling process by providing relevant information (e.g., information on the condition of the components), which eliminates the need for complex investigations of discarded products [37, p. 3895]. In addition to the components of the product, all information stored in the DT can also be reused by using it in the development of new products, and, information about the product can also play a role in the final disposal of potentially hazardous substances [57, p. 98].

6. IMPLICATIONS FOR MARKETING

Because marketing in the context of DTs hardly plays a role in literature, the question arises as to how this concept can be used in the marketing mix for consumer goods. We have analyzed the usage options of the DT in the product life cycle based on literature. Now it will be shown how these usage options influence the marketing mix for consumer goods. The marketing mix includes the operational decisions of a company to shape product policy, communication policy, distribution policy, and pricing policy.

6.1 Product policy

The product policy covers all business decisions relating to the customer-oriented design of existing and future products, considering entrepreneurial objectives. The subject of the product policy is the planning and implementation of product innovations and the maintenance of successfully established products [65, p. 12]. The use of the DT makes it possible to collect not only data on the functioning and the condition of the smart product, but also data on customer needs, customer behavior and customer demand.

DTs of consumer goods enable dynamic, situational product adaptation. They help with new product development, product variation and product diversification. They also serve product optimization, predictive maintenance and repair. DTs indicate the decreasing usage intensity, which signals to management that product diversification or product innovation is necessary. DTs also help in the development and provision of additional services to the customer.

6.2 Communication policy

The communication policy covers all decisions regarding the communication of the company in the market. This includes the use of communication tools such as media advertising, sales promotion, digital marketing, influencer marketing, platform marketing or direct marketing [65, p. 13].

Through the constant analysis of the user behavior of the customers, it is possible for companies to place individualized advertising tailored to the respective customer needs. For example, if wear is detected, new spare parts can be proposed to the customer. But recommendations for additional products and services to the existing consumer goods are also possible.

The simulation function of the DT can be used for product demonstrations in sales promotion.

6.3 Distribution policy

The distribution policy includes the design of the distribution system, the design of relationships with sales partners and key accounts as well as the design of sales activities. In the context of sales logistics, it is about ensuring the physical availability of the product to the customers. These are decisions about cooperation with sales agents and the design of warehousing and transport routes [65, p. 13].

DTs can be used to support sales bodies, such as sales offices and online platforms. In direct sales, the consumer good can be presented to the potential customer via simulations with the DT. Such simulations offer the customer the opportunity to test the product under almost real conditions, which increases credibility and the intention to buy.

Large savings and efficiency gains are possible through the use of DTs in sales logistics. DTs can reduce logistics processes and optimize packaging processes through real-time monitoring and other functions. DTs also monitor and optimize the work of logistics centers and warehouses in real time.

6.4 Pricing policy

The pricing policy covers all decisions regarding the price to be paid by the customer for a product [65, p. 13] and the determination of the conditions under which the product is transferred to the buyer’s possession.

DTs make it possible to determine customer benefits based on their useful life and intensity and to determine customer-oriented prices. By recording the usage behavior of different customers, spare parts, additional parts or new products can be offered at individual prices.

Discounts can be granted for the product link with the DT, for individual usage behavior or service use. For a customer who is noticed by the intensive use and care of his consumer goods, it can be assumed that the willingness to pay is higher than with average users. As a result, consumer goods can be offered to this customer at higher prices. This procedure corresponds to price differentiation by customer groups.

7. CONCLUSION

Our conceptual contribution is based on an extensive literature analysis. It shows how a DT works and in which phases and how DTs can be used in the life cycle of consumer goods. At the same time, we show in which areas of the marketing mix the use of the DT is beneficial for companies.

So far, DTs have only been used in very few companies that produce consumer goods. Therefore, the possibilities of using the DT for marketing have so far been relatively unexplored. How and whether a broad development and use of DTs for consumer goods should take place in the consumer goods industry is a future research question.

Companies need to identify the necessary skills to provide a DT. Interaction with DTs must also be geared to customer skills and competences. This results in another research question: Does the DT have to be different depending on the customer segment?

In marketing, it remains to be considered whether the costs of developing, implementing and using DTs meet the customer's wishes and are profitable.

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