PERFECT PRODUCT IN PERFECT INDUSTRY – DESIGN FOR LOGISTICS

Maciej Bielecki
Barbara Galińska
Aleksandra Polak-Sopińska

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Reviewed by:
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LIST OF ACRONYMS

BOM	Bill of Materials
CI	Continuous Improvement
DCA	Design Compatibility Analysis
DfA	Design for Assembly
DfD	Design for Delivery
DfDa	Design for Disassembly
DfC	Design for Cost
DfL	Design for Logistics
DfLC	Design for Life Cycle
DfE	Design for Environment
DfF	Design for Flexibility
DfM	Design for Manufacturing
DfMa	Design for Maintainability
DfMH	Design for Material Handling and Movement
DfN	Design for Network
DfO	Design for Obsolescence
DfP	Design for Packaging
DfQ	Design for Quality
DfR	Design for Recycling
DfS	Design for Sustainability
DfSv	Design for Services
DfSC	Design for Supply Chain
DfT	Design for Transportability
DfX	Design for eXcellence
DfV	Design for Variety
DP	Decoupling point
IL	Logistics Engineering
LSP	Logistic Efficiency of Product
NFC	Near Field Communication
PDCA	Plan-Do-Check-Act
PLS	Logistically Efficient Product
RFID	Radio-Frequency Identification

TLM	Total Logistics Management
TSL	Transport/Freight Forwarding/Logistics
TQM	Total Quality Management
URL	Uniform Resource Locator

INTRODUCTION

An informed analysis of any industry still driven by the third industrial revolution (e.g. computer-aided automation of flexible manufacturing systems) shows in many cases that product design plays a very important role in production processes. The strategies applied in the 1980s by industrial enterprises, whose prime objective was to eliminate any kind of waste in production processes (in line with the *Lean*[1] method), brought many production systems to a point where each subsequent investment to improve efficiency and productivity yielded an increasingly smaller effect. Therefore, engineers were compelled to look for solutions which, embedded in the final product, would make the processes of production, quality, logistics and logistic chain more effective and efficient. This is all the more important because at a time marked by ongoing challenges associated with the implementation of Industry 4.0. the role of the product in and of itself appears to be of key importance.

The presented study explores the topic of *Design for Logistics* as part of a broader concept of *Design for eXellence*. The effect of the work by the designers who address logistic considerations in product design is a logistically efficient product characterized more broadly within the concept of logistic efficiency of the product. Thus, this book deals with research on certain practical solutions in finished products that have been introduced in the process of their design and that contribute to facilitating logistic processes throughout the supply chain. It also marks the beginning of a scientific discussion on the problem of integrating logistic considerations into product design. At the same time, its universal character makes it suitable for researchers specializing in different areas related to logistics as well as for students pursuing various fields of study. It is also a valuable resource for practitioners since all of the main theoretical underpinnings of Design for Logistics are reviewed, discussed in an accessible manner, and illustrated with tables and figures.

The book is the result of the analysis of publications in the field of logistics, design supporting excellence and logistics, and many years of experience of scientists and practitioners, including the authors. Its subject matter falls within the scientific discipline of "management and quality sciences" and is strongly tied to contemporary issues in logistics. It is an interesting study on the issue of Design for Logistics, the physical manifestation of which is a logistically efficient product.

[1] Later described by Womack and Jones – Womack J., Jones D., *Lean Thinking. Banish waste and create wealth in your corporation*, Free Press, New York, London, Tokyo, Sydney, Singapore, 2003.

Similarly to Mather[2] who, as a result of his empirical experience in launching a product on the market, turned his attention to the notions of Design for Logistics and a logistically efficient product, the authors of this study, not having referred yet to the body of research on the issue in question, encountered an emerging research problem.

The idea to study logistic efficiency of products resulted from an 'unintentional' participant observation in the process of consumer goods purchase and conclusions drawn on its basis. The purchase included two events separated in time (one in 2005 and one in 2011). It involved an identical product, whose logistical parameters differed substantially.

From the point of view of the enterprise, the modifications in the parameters of the product resulted in the following logistic advantages: the size of the packaging was reduced, redundant customer service and product handling activities in the in-store warehouse were eliminated, product competitiveness was enhanced due to its lowered price. From the perspective of the customer, the main benefits were lower price, a much simpler purchasing process, and easier transportation of the product home (smaller-size packaging).

The conclusion following from the presented example was simple. The change in the design, the packaging process, and the extent of the assembly of the finished product (product assembled by the buyer) resulted in certain advantages, including very important logistic advantages for both the manufacturer (and the store) supplying the furniture as well as the customer. This first-hand experience became an inspiration for seeking similar design solutions to streamline logistics on the part of the enterprise and of the end consumer. It was that which triggered research work on logistic efficiency of the product and a logistically efficient product.

The subject matter of Design for Logistics and logistic efficiency of products is a very broad and multidisciplinary issue, which doubtless had a great impact on the selection of content that ultimately shaped the way this work is structured. The book has two main parts:

- theoretical part (chapters 1 and 2);
- practical part (chapter 3).

The first chapter, forming the theoretical part of the work, deals with three primary issues relevant to the discussed topics, i.e.: product design, product as a subject to design, and design for excellence (DfX). It is mainly based on the output of authors directly involved in design studies, i.e. Dietrych[3] and Gasparski[4], concurrent engineering – works by Pennel, Winner[5],

[2] Mather H., *Design for Logistics (DfL) – the next challenge for designers*, Production and Inventory Management Journal, Vol. 33 (1), 1992, pp. 7-9.
[3] Dietrych J., *System i konstrukcja*, Wydawnictwa Naukowo-Techniczne, Warszawa, 1985.
[4] Gasparski W. (ed.), *Projektoznawstwo. Elementy wiedzy o projektowaniu*, Wydawnictwo Naukowo-Techniczne, Warszawa, 1988; Gasparski W., *Projektowanie. Koncepcyjne przygotowanie działań,* Państwowe Wydawnictwo Naukowe, Warszawa, 1978.
[5] Winner R., Pennel J., *The role of concurrent engineering in weapons system acquisition*, Institute for Defense Analisys, Alexandria, 1998.

Xiong and Zhang[6], and the model approach to design in the context of production engineering as formulated by Durlik and Santarek[7].

Among literature items discussing the main points of the DfX concept are Becker and Witts[8], Boothroyd and Dewhurst[9], Eppineger and Urlich[10], and - as for Polish authors, Duda[11] and Rutkowski[12].

The second part of the theoretical portion of the book explores the issue of Design for Logistics (DfL) and the concept of logistic efficiency of the product. The discussion concerning DfL is based on Mather[13], Dowlatshahi[14], and Domin, Mark, Wisner[15]. A deductive and inductive approach to DfL in the context of logistic efficiency of the product is presented. Analysis of the relations between product parameters, logistic phases and processes is also performed. Primary product parameters (attributes, properties, architecture) are defined and relations between them are discussed. In this part of the work, references are made to the previously mentioned Dowlatshahi and Mather as well as Korzeniowski[16], Mokrzyszczak[17] and Sarjusz-Wolski[18]. The part of the book that deals with the concept of logistic efficiency of products begins with a characterization of a logistically efficient product. The idea has evolved from the research and observations that one of the authors (Bielecki) has conducted since 2011 The part of the book that deals with the concept of logistic efficiency of products begins with a characterization of a logistically efficient product. The concept has emerged from the research and observation by one of the authors (Bielecki), that he has been conducting since 2011 on the parameters of products that are advantageous for logistic processes[19]. The last of the subchapters of this part of the study is concerned with considerations of determinants of logistic efficiency of the product, presenting the model of logistic efficiency of the product in the

[6] Xiong G., Zhang Y., *Concurrent Engineering systematic Approach and Application*, Thinghua Science and Technology, Vol. 1, No. 2, 1996, pp. 185-192.

[7] Durlik I., Santarek K., *Inżynieria zarządzania III. Naukowe, techniczne i inwestycyjne przygotowanie produkcji wyrobów wysokiej techniki*, Wydawnictwo C.H. Beck, Warszawa, 2016.

[8] Becker J.M.J., Wits W.W., *A Template for Design for eXcellence (DfX) Methods,* [in:] Abramovici M., Stark R. (eds.), *Smart Product Engineering. Lecture Notes in Production Engineering.* Springer-Verlag, Berlin, Heidelberg, 2013.

[9] Boothroyd G., Dewhurst P., *Product Design and Assembly, Designer Handbook*, University of Massachusetts, Dept. of Mechanical Engineering, 1983.

[10] Ulrich K.T., Eppinger S.D., *Product design and development, 4th Edition,* McGraw-Hill, 2007.

[11] Duda J., *Zarządzanie rozwojem wyrobów w ujęciu systemowym*, Wydawnictwo Politechniki Krakowskiej, Kraków, 2016.

[12] Rutkowski I., *Rozwój nowego produktu. Metody i uwarunkowania*, Polskie Wydawnictwo Ekonomiczne, Warszawa, 2011.

[13] Mather H., *Design for Logistics (DfL) – the next challenge for designers …*, op. cit., pp. 7-9.

[14] Dowlatshahi S., *The role of logistics in concurrent engineering*, International Journal of Production Economics, Vol. 44, 1996, pp. 189-199.

[15] Domin H.E., Wisner J., Marks., *Design for Supply Chain.* Retrieved February 3, 2018 from www.sdcexec.com/article/10289661/design-for-supply-chain.

[16] Korzeniowski A. (ed.), *Magazynowanie towarów niebezpiecznych, przemysłowych i spożywczych*, Instytut Logistyki i Magazynowania, Poznań, 2006.

[17] Mokrzyszczak H., *Logistyka. Podstawy procesów logistycznych*, Wydawnictwo WIG, Białystok, 1998.

[18] Sarjusz-Wolski Z., *Sterowanie zapasami w przedsiębiorstwie,* Polskie Wydawnictwo Ekonomiczne, Warszawa, 2000.

[19] Bielecki M., *Conditions of products logistically fit in small manufacturing enterprises*, [in:] Lewandowski J., Sekieta M., Jalmużna I. (eds.), Logistics aspects of management in the organization, Wydawnictwo Politechniki Łódzkiej, Łódź, 2011, pp. 7-23; Bielecki M., *The Logistical Efficiency of the Product in Logistics Strategies of Manufacturing Enterprises*, Carpathian Logistic Congress, Congress proceedings, CD edition, Jesenik, Czechy, 2012.

context of product parameters from the viewpoint of both the organization as well as the consumer. This part of the analysis also includes a diagram of potential implications of selecting a specific variant of optimization of product parameters in the model of logistic efficiency.

The third chapter, which forms the practical part of the book, presents a model of manufacturing company logistics based on the logistic efficiency of products. Metrics and indices are proposed that allow for analysis and evaluation of selected aspects of logistic efficiency of products. In this section of the book, referred to are studies by Ishii and Martin[20], Martin, Mather, and, among Polish authors, by Bogdanowicz[21], Nowicka-Skowron[22], and Twaróg[23]. Further, research methodology for studying logistic efficiency of the product is explained. Reference is made to publications by Bendkowski[24], Dul and Hak[25], Eisenhardt[26], Dul, Eisenhardt, Elram[27], and Flyvbjerg[28]. Finally, an approach to the selection of research subjects is presented along with a synthetic summary of the results of the study on logistic efficiency of products[29].

[20] Martin M., Ishii K., *Design for Variety: developing standardized and modularized product platform architectures*, Research in Engineering Design, Vol. 13, No. 3, 2002, pp. 213-235.
[21] Bogdanowicz S., *Podatność. Teorie i zastosowanie w transporcie*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2012.
[22] Nowicka-Skowron M., *Efektywność systemów logistycznych,* Polskie Wydawnictwo Ekonomiczne, Warszawa, 2000.
[23] Twaróg J., *Mierniki i wskaźniki logistyczne,* Biblioteka Logistyka, Instytut Logistyki i Magazynowania, Poznań, 2003.
[24] Bendkowski J., Dohn K., *Logistyka. Pisanie pracy dyplomowej, kwalifikacyjnej. Zasady pisania, studia przypadku,* Politechnika Śląska, Gliwice, 2015.
[25] Dul J., Hak T., *Case Study Methodology in Business Research*, Butterworth--Heinemann, Oxford, 2008.
[26] Eisenhardt K., *Building Theories from Case Study Research*, Academy of Management Review, Vol. 14, No. 4, 1998, pp. 532-550.
[27] Ellram L., *The use of the case study method in Logistics Research,* Journal of Business Logistics. Vol. 17, No. 2, 1996, pp. 93-138.
[28] Flyvbjerg B., *Five Misunderstandings About Case-Study Research*, Qualitative Inquiry, Vol. 12, No. 2, 2006, pp. 219-245.
[29] Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2018.

1. DESIGN FOR EXCELLENCE

1.1. Product design – literature review

Design of a new product or the improvement of an existing one is a rather complex matter. Any new product should not only meet very heterogeneous customer requirements but also ensure that the organization achieves certain profitability and growth. Given the upward trend towards cost minimization, seeking savings in processes has ceased to be sufficient. As early as the 1960s[30], it had become apparent that an array of product characteristics and properties existed which directly or indirectly impacted on activities such as manufacturing and assembly. Along with new challenges arising from industrial development, further areas followed, including logistic issues pertaining to procurement, production, distribution, returns and disposal. Product attributes and qualities, in many cases, may ultimately hinder the possibility of implementing technical and organizational advancement, which directly impinges on the effectiveness of certain decisions. Therefore, the domain of product design and development to support a variety of processes, especially for manufacturing companies, is of great importance.

In order to properly address the topic of Design for Logistics, selected theoretical considerations related to design are presented first. Since a wealth of Polish literature on the subject is available, conceptual approaches by Polish researchers and designers are discussed.

As early as 1961, on account of Kotarbiński, attention was drawn to praxeological nature of design. According to the above mentioned author, design is about trying to identify certain conditions sufficient to determine states of affairs, based on certain objective (formal) relationships[31]. Clearly, what follows from this definition is the nature of design as a preliminary, or preparational, if you like, activity. If design is a preparational activity, then it is important to note here that areas of reference should be specified for the process with regard to which the preparational activity is carried out. The praxeological character of design activities was also stressed by Simon, an economist[32], who claimed that design meant any action that transformed one state into another, a preferred one, and emphasized that the intellectual exercise involved in the creation of new things in no way differed from that made by a doctor who aimed to prescribe a medication to a patient. He also pointed out that one of the main tasks of schools of technology, architecture, and others was actually to teach design. Therefore,

[30] One of the first industry publications encouraging changes in product characteristics and qualities to improve production efficiency was, e.g. *Manufacturing Producibility Handbook,* General Electric Co., Manufacturing Services, Schenectady, New York, 1960.
[31] Kotarbiński T., *Elementy teorii poznania, logiki formalnej i metodologii nauki,* Ossolineum, Wrocław-Warszawa-Kraków, 1961, p. 544.
[32] Simon H. A., *The Sciences of the Artificial,* Cambridge, Mass MIT Press, p. 70 [cited in] Gasparski W., *Projektowanie. Koncepcyjne przygotowanie działań …*, op. cit., pp. 68-69.

putting design in a praxeological context, where it is governed by principles of efficient and purposeful action, should not raise doubts.

What should also be accentuated in the analysis of design is its systemic character. Gasparski[33] is right to observe that the systems approach to design clearly points to purposeful design and organization of interactions of the designing system with the designed system, whose overarching goal is to improve. The same author goes on to list three principal contexts/frames of reference for design.

The first of the contexts, of the designed object, has the resulting creation as the key element. The second of the contexts means the process of arriving at a specific solution (pragmatic aspect), i.e. the category of the designed object is expanded to include a set of procedures for the conduct of the design process. The third context – of methodology – demonstrating how a problem can be solved not by identifying a single perfect solution, but by identifying a set of characteristics of a perfect agent – Figure 1.

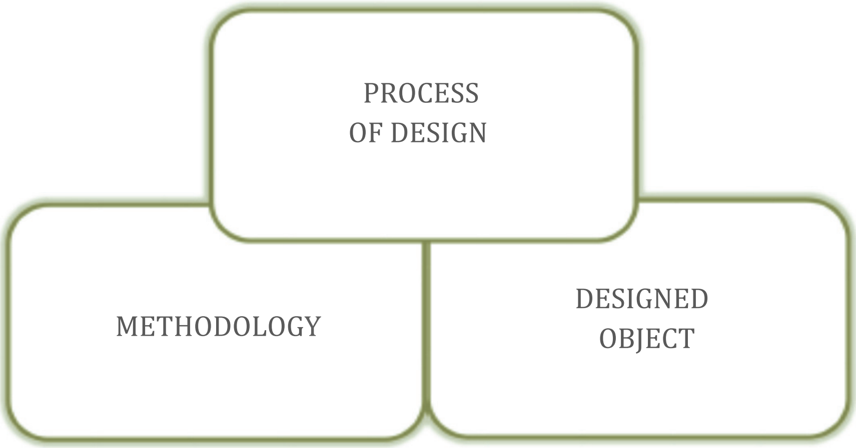

Figure 1. Three fundamental contexts/frames of reference for design
Source: compiled by the authors based on Gasparski W., Projektowanie. Koncepcyjne przygotowanie działań, Państwowe Wydawnictwo Naukowe, Warszawa, 1978, pp. 70-71.

In another study[34], Gasparski modified to some degree the discussed configuration pointing out the following three fundamental areas of reference (contexts) of design:

- context of the agent (the actor of design) – the designer and methods;
- context of the artifact (the object of design);
- context of activity (the process of design).

[33] Gasparski W., *Projektowanie. Koncepcyjne przygotowanie działań ...*, op. cit., p. 69.
[34] Gasparski W. (ed.), *Projektoznawstwo. Elementy wiedzy o projektowaniu ...*, op. cit., pp. 24-25.

The most important consideration for this publication is the context of the designed object construed as a product with an improved set of features and qualities which render it prepared to be functional throughout its life cycle (from design to disposal, and through the economic and marketing phases of introduction, growth, maturity, and decline)[35]. The ultimate added value of design activities will be the change in the designed object[36].

One aspect that is often emphasized in any design process is the purpose of modification. In principle, all designed changes should be underpinned by scientific and practical knowledge, which dictates that they be rational. If human agency in conceptualization of changes is taken as a primary criterion, changes can be categorized into intended and unintended. Intended changes are those that have been deliberately effected by a human being. The latter kind is an unexpected consequence of the former kind of change. If the genuineness of changes is assumed to be the principal criterion, changes can be divided into genuine (occurring in the things undergoing change) and apparent (eliciting a perception of change). Another aspect of the kind of changes that are under scrutiny here involves their utility - usefulness of the effects of change. From a praxeological point of view, according to Gasparski, changes may take on a positive or negative value, as may aesthetic and ethical evaluation of changes[37].

From the perspective of logistics, it must be asserted that, in principle, designed changes should be changes proper, i.e. rational, intended, genuine (the nature of logistic processes will immediately verify their genuineness), positively utilitarian, ethical, and aesthetic, all at the same time[38].

Gasparski also identifies several fundamental goals of design processes. Referencing Nadler[39], he lists three principal aims of design activities concentrating on the maximization of:

- the effectiveness of the proposed solutions;
- the efficiency in resource use;
- the viability of implementing specific solutions.

Consequently, the change designed to create a new product as well as the change meant to modify an existing one should both represent change proper taking into account optimization of the three primary goals of design activities – Figure 2.

[35] Santarek K., Skołud B., Kosieradzka A., *Organizacja i zarządzanie produkcją oraz usługami,* [in:] Knosala R. (ed.), *Inżynieria produkcji. Kompendium wiedzy*, PWE, Warszawa, 2017, p. 31.
[36] Gasparski W. (ed.), *Projektoznawstwo. Elementy wiedzy o projektowaniu …*, op. cit., p. 142.
[37] Ibid., pp. 145-147.
[38] Ibid., p. 147.
[39] Nadler G., *The planning and Design Approach,* Willey, New York, 1982.

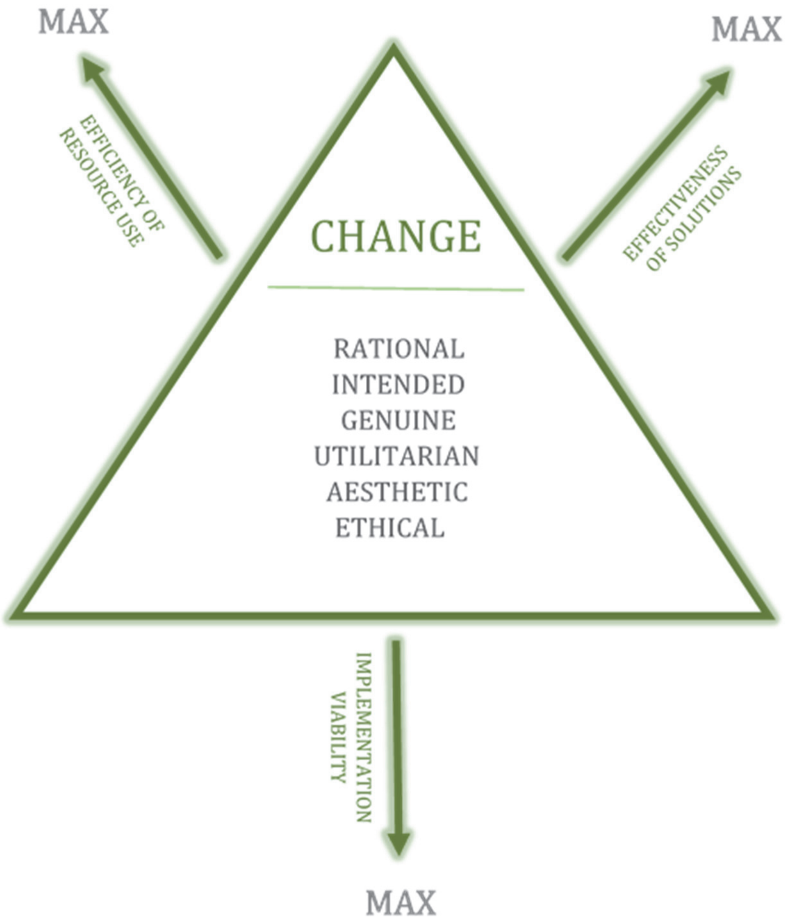

Figure 2. Primary goals of design activities on change proper
Source: compiled by the authors based on Gasparski W. [ed.], Projektoznawstwo. Elementy wiedzy o projektowaniu, Wydawnictwo Naukowo-Techniczne, Warszawa, 1988, pp. 145-147.

Another Polish author whose contribution to the theory of design and engineering sciences must not be ignored is Janusz Dietrych. In his definition, designing consists in answering two underlying questions, i.e.:

- what is the purpose of designing?
- what does it involve?

Hence, the author refers to design as an activity which in the most authoritative way determines technical effectiveness of the fulfillment of needs[40]. By the same token, he points out that design should give priority to social criteria, while leaving it to engineering to take account of economic and technical criteria. This approach to design is reflected in many different conceptions of management, for example in the model of *corporate social responsibility* (CSR)[41].

[40]Dietrych J., *System i konstrukcja* ..., op. cit., p. 161.
[41] More on the CSR concept can be found in Stefańska's review – Stefańska M., *Podstawy teoretyczne i ewolucja pojęcia społeczna odpowiedzialność biznesu (CSR),* Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, Issue 288, Wrocław, 2013, pp. 198-211.

Nevertheless, it should be recognized that business in the 21st century do not necessarily consider social criteria a priority in deciding on specific solutions. In many cases, cold calculation of economic and technical factors seem to prevail over social issues.

In summary, irrespective of which of the previously discussed literature items outlining design methodology we would attempt to relate to in this work, each of them draws attention to a model configuration of the design system. Each of the authors also draws attention to a need as a trigger for the design process. What also deserves to be noted is a certain tendency of problem-based design that follows from the views presented by Gasparski. Externalization of boundary conditions (maximizing the goal while minimizing the cost of a solution) is achieved by modifying existing solutions, which leads to an evolution of certain solutions.

Formal evaluation of a functional object, concerning the subject of the activity, should in essence rely on a systemic criterion that takes into account all parameters and activities that meet particular needs. Thus, design is a process of creation, development of a certain plan of a technical object, process or a system, whereas a design is an outcome of that effort. A design should meet a number of essential prerequisites, i.e.[42]:

- it should achieve the goals set for it;
- these goals should be accomplished in a clearly defined environment;
- the goals should make use of existing knowledge resources in the form of a set of elementary solutions (well-established, typical, standardized);
- while maintaining boundary conditions (constraints) in the form of technical, financial, organizational, environmental, social, etc. constraints.

Design as such is generally driven by needs. Dietrych offers the following system of operational elements of the process of the fulfillment of needs:

1) a need (its recognition, successful identification) – as a key element of the process of need fulfillment;
2) designing (formal description of the need is the blueprint for designing);
3) engineering (the outcome of designing provides a framework for engineering – laying down specifications for manufacturing);
4) manufacturing;
5) use[43].

[42] Dietrych J., *System i konstrukcja ...,* op. cit., pp. 34-35.
[43] Ibid, pp. 34-35.

It is worth noting at this point that the presented content rather clearly points to the necessity of cooperation between the designer and the engineer, since the value of the work in both areas will ultimately be decided by the effectiveness of the solution in meeting the needs.

This idea is embedded in the concept of Concurrent Engineering (CE), a definition of which emerged in 1988 in the USA. It was then that the Institute for Defense Analysis described CE as a systematic method of concurrent design of products that took into account the process of their manufacturing and other product support processes. CE is therefore a systematic approach to the problem of integrated and concurrent design of products and product-related processes, inclusive of manufacturing and other associated processes. Its aim is to introduce designers from the very beginning (make them aware of, familiar with) to the concept of the product life cycle, through to the product ultimate disposal[44].

Xiong and Zhang[45] furthermore single out the following three major features of CE, namely that:

- it is part of the Product Development Process;
- it applies the concept of Computer Integrated Manufacturing Systems (CIMS) with an emphasis on integrating design, manufacturing, and technology;
- it derives benefits from balancing the four basic considerations: customer requirements, organizational requirements, communication, and product life cycle.

Product design, in a similar context, is also discussed by Durlik and Santarek[46], as well as Simon[47]. According to the these authors, the design process compels the designer to embrace multi-dimensionality as an immanent feature of the process. Taking into account technical, technological, functional, aesthetic, economic, and social aspects is critical from the standpoint of the process itself as well as of the designed object. This means that the design process will be the more effective the more design aspects it is able to address and attain at the same time their extremes. It is important to note here that this approach fits seamlessly with the concept of concurrent design.

All definitions of design refer to the notion of a system and system character of the design process. Assuming - along with the cited authors - that systems approach is a distinctive feature of design, it appears useful to establish what the term 'systems' actually denotes.

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[44] Winner R., Pennel J., *The role of concurrent engineering in weapons system acquisition …*, op. cit., p. 4.
[45] Xiong G., Zhang Y., *Concurrent Engineering systematic Approach and Application …*, op. cit., p. 186.
[46] Durlik I., Santarek K., *Inżynieria zarządzania III. Naukowe, techniczne i inwestycyjne przygotowanie produkcji wyrobów wysokiej techniki …*, op. cit., pp. 97-98.
[47] Simon H. A., *The Sciences of the Artificial …*, op. cit., p. 37.

Indeed, the hallmark features of the systems approach are inclusiveness, comprehensiveness, essentialism, structuralism, contextualism, and purposefulness[48]. Inclusiveness means examining a phenomenon as a whole, which implies that the designed object must not be considered solely from one single point of view. Holistic nature of a product should take into account not only the needs of the final customer - the consumer, but also of a range of internal customers who represent specific loci of added value creation. Comprehensiveness is understood as recognition of a variety of feedback and inter-relations between internal phenomena. Essentialism is construed as extraction of the essence of a studied phenomenon consisting in specifying sets of essential, derivative, and incidental quantities. The last two sets are secondary factors, where derived quantities stem from essential quantities, whereas incidental quantities follow from derived quantities. Structuralism is the next trait of the systems nature of the design process. It is mainly concerned with considering a phenomenon also through the prism of the value of its structure, which is understood as unifying and unvarying. Contextualism, i.e. analyzing systems in relation to other phenomena, is another feature listed by Gasparski. Purposefulness, which means interpreting phenomena through the lens of their purposefulness (usefulness), is highlighted as the key characteristics of the entire approach.

Since the central theme of this publication is the product, conceived as a good (an outcome of manufacturing), attention should first be drawn to the variety of ways found in the literature in which the product is defined as an entity subject to design.

1.2. Product in the process of design

In analyzing the process of design of both products and systems, it is worth noting that there are considerable differences and similarities that arise from the features and qualities of products and systems. These differences are mainly attributable to the functional approach to the product itself, i.e. perceiving it only from the viewpoint of the needs of a particular area of a branch of science. For example, a number of product definitions have a marketing background (they are strictly related to economic and market thinking – the realm of social sciences), whereas others have their roots in industry and concentrate on product engineering (the realm of technical sciences).

[48] Gasparski W. (ed.), *Projektoznawstwo. Elementy wiedzy o projektowaniu …*, op. cit., pp. 192-197.

One example of the first of the discussed definitions, one that derives from a marketing approach, is provided by Kotler[49]. He defined the product as everything that can be offered to someone to fulfill their want or their need. Within this approach, customer needs become a key element determining the creation of a product, although it is important to bear in mind that this definition lacks the part that would address the way the need is to be fulfilled and its cost-effectiveness. In the context of this study, the marketing approach, although highly meaningful, is nevertheless of secondary importance. The emphasis will instead be on an aspect strongly related to production engineering. The product will be considered from the perspective of its design in the context of the systems approach to all engineering activities associated with its production, its quality, and above all, logistics.

The product within the framework of design is defined as the object of design. Gasparski[50] draws attention to the difference between the notions of the designed object and the object of design. He quite accurately observes that the concept of the designed object often includes a number of assumptions, starting with the anticipation that the customer is able to articulate their needs and ending with the assumption that the designed object is viewed as static. The latter approach in particular limits the possibility of appraising potential and multifaceted relations that the object may be involved in because they are disregarded. This understanding of the product, as the designed object, leads to a situation where the designer's unawareness of possible interactions the product may enter into in each phase of its development may generate an array of negative consequences for direct and indirect beneficiaries of the final outcome of design. For that reason Gasparski resorted to the notion of the object of design[51] interpreted as a cut-out fragment of reality contemplated by the designer. However, the concept of how to change this reality or its fragment is not merely limited to the object itself; instead it also includes the consequences that this change entails. Thus interpreted, the designed object is merely a part of the object of design which, in its essence, becomes a broader concept. One could say that the object of design grows into a set of designed objects linked to one another by the principle of unity of the outcome of design.

The Encyclopedia of Materials Management[52] describes the product as a material good that is a result of the production process carried out by manufacturers and may take the form of: semi-finished products (intermediate products intended for further processing), elements of a more complex product, and finished goods. The definition places the product in an

[49] Kotler P., *Marketing. Analiza, planowanie, wdrażanie i kontrola*, Gebethner i Ska, Warszawa 1994, p. 7; 404.
[50] Gasparski W. (ed.), *Projektoznawstwo. Elementy wiedzy o projektowaniu …*, op. cit., pp. 154-157.
[51] Ibid., p. 155.
[52] *Encyklopedia gospodarki materiałowej,* Państwowe Wydawnictwo Ekonomiczne, Warszawa, 1989, p. 406.

engineering context and thus points to the fact that products frequently constitute an element of a more complex whole. It follows that the identification of customer needs will proceed in at least two stages. The first and most important stage will concern the final customer, while the second will apply to the next recipient of a finished good for whom it will be part of a more complex product.

Durlik and Santarek define the product as a good or a service that represents a set of benefits (utility) for the end user[53]. The authors do not mention a set of benefits and uses that the product should generate in view of subsequent processes required to deliver the product to the market. The same authors identify two principal stages in the development of a new product, making a distinction between:

- technical and engineering activities centered around research and development, product design, product construction, prototyping, technological and investment planning;
- marketing and economic activities associated with market research and marketing analyses, feasibility studies, determination of break-even points, cost accounting and cost effectiveness analysis, marketing activities related to releasing the product on the market as well as after-sales support[54].

The domain of marketing and economic activities therefore serves mainly as a tool to identify the needs of the final customer, while the domain of economic activity deals with analyzing profitability of the undertaken activities.

As the presented study refers mainly to issues in logistics, a definition of the product directly relevant to logistics should also be provided. Gołembska[55] in her attempt to define a logistic product states that a logistic product is a set of customer expectations as to the quality and form of products (goods and services) which are an element of the logistic system. Thus, on the one hand, the said products are elements of the flow in the logistic channel, while on the other hand, their economic character enables all participants in the system of logistics to make a profit.

From the point of view of the commodity status of the logistic product, it should be considered in terms of its physical and chemical characteristics, i.e. factors such as weight, form, shape, transportability, as well as economic aspects strictly related to commercial exchange (price, substitutability, complementarity, etc.). Gołembska also underscores that the overriding goal of the logistic system in the organization is to prepare such technological and

[53] Durlik I., Santarek K., *Inżynieria zarządzania III. Naukowe, techniczne i inwestycyjne przygotowanie produkcji wyrobów wysokiej techniki* …, op. cit., p. 47.
[54] Ibid, p. 48.
[55] Gołembska E. (ed.), *Kompendium wiedzy o logistyce*, Wydawnictwo Naukowe PWN, Warszawa Poznań, 2002, p. 53.

economic foundations of this system that the customer, in keeping with their expectations, could receive the ordered product from the supplier in accordance with the logistic principle of Shapiro and Heskett[56] since these authors proposed that the definition of logistics could be framed with the seven main points based on the word "right":

- delivering the right product;
- in the right condition;
- to the right place;
- at the right time, in the right quantity, and of the right quality;
- at the right cost.

Note that when logistic context of the product is analyzed, each of the seven Rs will be related to specific logistic processes associated with phase-based approach to them (transport, storage, packaging, inventory management, and order handling). Gołembska citing Pfohl[57] also distinguishes three primary systems of the transformation of goods in the process of becoming a logistic product:

1) acquisition of goods related to the qualitative transformation (extraction, processing, manufacturing);
2) distribution of goods, related to packaging, completion, storage, and movement;
3) consumption of goods as logistic products.

The proposed classification clearly fails to include issues related to returns and disposal of used goods, which, especially in view of the concerns arising in the 21st century, is a major challenge.

Ulrich and Eppinger note[58], that performance of product designers is always assessed in five dimensions, i.e.: product quality, manufacturing costs, time spent on design and development activities, cost of design and development work, and development opportunities understood as an asset for the organization allowing it to develop products increasingly more effectively and efficiently.

Product design and development entail that the designer should take many variables into consideration. Ulrich and Eppinger argue[59] that the main determinants of product design and development are marketing, design, and manufacturing functions. Marketing functions enable the establishment of a number of conditions related to the market concept of the product, i.e. identification of customer needs, price targets, market segments, and elements related to the

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[56] Shapiro R. D., Heskett J. L., *Logistics Strategy: Cases and Concepts*, West Pub. Co., Minnesota, 1986, p. 6.
[57] Pfohl H., *Systemy logistyczne. Podstawy organizacji i zarządzania,* Instytut Logistyki i Magazynowania, Poznań, 1998.
[58] Ulrich K.T., Eppinger S.D., *Product design and development …*, op. cit., p. 3.
[59] Grębosz M., Kazimierska M., *Wspomaganie komputerowe w zarządzaniu cyklem życia produktu,* Mechanik, No 7, p. 694.

promotion of a product - MIX Marketing[60]. Design functions play a key role in defining the physical form of the product that best meets customer expectations taking into account engineering design issues (mechanical, electrical, firmware, etc.) as well as industrial design issues (aesthetic and ergonomic factors, etc.). Manufacturing functions are first and foremost responsible for organization of the manufacturing process, often including the purchase, delivery, and installation of finished products at the end user's.

Whereas Duda[61] proposes to analyze the development of the product in terms of its life cycle in which one can distinguish the phase of production preparation (related to marketing, engineering and technological design, prototyping, and organizational design) and the phase of production and use that encompasses procurement and manufacturing, distribution and sales, use and service, and disposal and recycling. This way, the production preparation phase proves to be a key element in the work of designers, the consequences of which will be salient throughout the phase of production and use.

Ulrich and Eppinger, who have already been referred to, conceptualized the process of product development as proceeding in six primary phases, with certain actions performed during each one of them – Table 1.

[60] The concept of the 4Ps marketing mix (product, place, price, promotion) was put forward by McCarthy in 1960 – McCarthy E.J., *Basic Marketing, a Managerial Approach*, R.D. Irwin, Homewood-Illinois, 1960.
[61] Duda J., *Zarządzanie rozwojem wyrobów w ujęciu systemowym …*, op. cit., p. 27.

Table 1. Phases of product design and development from the perspective of various concepts and methods to support the process

<table>
<tr><th>Phases of product development process</th><td colspan="12"></td></tr>
<tr><td>Planning</td><td>Product development plan</td><td colspan="10"></td><td rowspan="6">Managing projects / Product development economics / Intellectual Property and patents / Processes of development and organization</td></tr>
<tr><td>Concept development</td><td></td><td>Identification of customer needs</td><td rowspan="2">Establishing product specification</td><td>Concept generation</td><td>Concept selection</td><td>Concept testing</td><td rowspan="2">Conceptual construct of the product</td><td rowspan="3">Industrial design</td><td></td><td rowspan="5">Prototyping</td><td rowspan="5">Analysis and evaluation of the construct</td></tr>
<tr><td>System-level design</td><td></td><td></td><td colspan="3"></td><td rowspan="4">Design for manufacturing</td></tr>
<tr><td>Designing the product proper</td><td colspan="7"></td></tr>
<tr><td>Testing and refinement</td><td colspan="8"></td></tr>
<tr><td>Production</td><td colspan="8"></td></tr>
</table>

Source: compiled by the authors based on Ulrich K.T., Eppinger S.D., Product design and development, 4th Edition, McGraw-Hill, 2007, p. 9.

The different phases specified by Ulrich and Eppinger[62] begin with the planning process, the primary objective of which is to select the object of design and define strategic guidelines for the entire process. The second phase, the development of the concept, may take a generic, spiral, and complex system form. Essentially, these three forms differ in how the design process, consisting of designing, prototyping, and validation, is performed. In the generic form, these three processes proceed in series. In no way, however, does this change the fact that these processes are iterated to form a spiral system - not unlike in Deming's Plan-Do-Check-Act (PDCA) cycle (or, as some authors would have it, Shewart-Deming's[63]), the processes of design, prototyping, and validation are repeated multiple times until the desired outcome is

[62] Ulrich K.T., Eppinger S.D., *Product design and development …*, op. cit., pp. 12-16.
[63] Hamrol A., Zymonik Z., *Zarządzanie jakością,* [in:] Knosala R. (ed.), *Inżynieria produkcji. Kompendium wiedzy …*, op. cit., p. 579.

achieved. For the complex system form, the design, prototyping, and verification processes run concurrently, in several design teams.

The system-level design phase is meant to take into account technological, economic and social considerations, therefore, it is, in fact, a pivotal point in engineering design. The guidelines derived from the considerations that have been factored in form the groundwork for the design of the product proper. The testing and refinement phase eliminates any underlying flaws that may not have been identified during the preceding design work, thus providing an output complete with documentation (much more often electronic than paper) to launch production. Where methods and concepts supporting product planning and development are concerned, the establishment of a product development plan is primarily focused on the selection of a certain product to be developed, and the starting point should be the formulation of strategic objectives for the selected product as a new design. Identification of customer needs, establishment of design objectives, generation and selection of solutions, and testing of solutions are the core processes of the conceptual development of a product. The aim of these activities is to select a particular product concept, together with a list of its intended functionalities, that meets the strategic objectives for the product. Conceptual construct of the product involves the process of converting the objectives into specific physical solutions, as well as analyzing how these solutions may entail the need to modify the product, the variability of the product itself, standardization of parts, production costs, etc. Thus, conceptual construct of the product provides direction for the industrial design process that takes into consideration the interaction between the new product and a human being[64]. Therefore, in industrial design attention is turned to aesthetic, ergonomic, etc. aspects of the developed product[65],[66]. Another of the presented notions concerns design for manufacturing, i.e. application of such solutions to the designed product as to reduce its manufacturing cost. Prototyping allows for verification whether all objectives resulting from previous processes have been effectively incorporated into the designed product. Analysis and evaluation of the construct involves analyzing and evaluating the robustness, durability, and reliability of the prototype. Of course, all activities should be coordinated through appropriate project management tools and take economic aspects of the entire design process into account. An important element emphasized by the authors is also to protect the intellectual value of the design by, for example, patenting any solutions that may prove to be of crucial importance to the company[67].

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[64] Ulrich K.T., Eppinger S.D., *Product design and development …*, op. cit., pp. 9-10.
[65] Wickens C.D., *Engineering Psychology and Human Performance*, 2nd ed., New York: Harper Collins, 1992.
[66] Butlewski M., *Projektowanie ergonomiczne wobec dynamiki deficytu zasobów ludzkich*, Wydawnictwo Politechniki Poznańskiej, Poznań, 2018.
[67] Ulrich K.T., Eppinger S.D., *Product design and development …*, op. cit., pp. 9-10.

Batalha[68] presented a synthetic inventory, as he called it, of integrated factors impacting on product R&D processes. The inventory includes the following:

- design factors:
  - organization standpoint (e.g. goals of the organization, its know-how, working conditions, economics, etc.);
  - society standpoint (e.g. laws and regulations, norms and standards, resources, patents);
  - designer standpoint (e.g. individual traits, skills, habits, etc.);
- production factors:
  - production process (feasibility, economics, workplace layout);
  - assembly process (the same as for production process);
  - testing;
- sales factors (market, sales policy, competition, packaging[69], transport and warehousing);
- use related factors:
  - user (past experience, technological literacy of the user, labor cost, utility);
  - environment (effect of the product on the environment and of the environment on the product);
  - use (practicality of functions, character of functions, reliability, serviceability, etc.);
- maintenance related (product structure, availability of spare parts, replaceability of spare parts);
- related to product withdrawal from the market (environment and recycling).

However, the factors proposed by Batalha appear to be presented somewhat chaotically. First of all, such aspects as e.g. economics are listed on a number of occasions, while selected logistic processes are classified by the author within the sales domain. Note also that the featured factors essentially fail to adequately capture customer expectations which, from the perspective of the design of the final product, play a key role.

1.3. Assumptions and application of Design for eXcellence

One of the newer and continuously evolving approaches to design is the concept of Design for eXcellence - DfX. It is inextricably linked to the concepts of product design and development. The DfX concept, in its premise, concentrates on consolidating a set of a variety

[68] Batalha G., *Design for X – design for excellence*, Scientific International Journal of the World Academy of Materials and Manufacturing Engineering, Vol. 6 (12), 2012, p. 10 – Open Access Library, Vol. 6 (12), 2012. Retrieved May 23, 2018, from http://www.openaccesslibrary.com/vol12/1.pdf
[69] PN-O-79021:1989 - Opakowania – System wymiarowy, 1989.

of design methods aimed at specific operational objectives. The first concepts of design for special purposes geared towards manufacturing, assembly, and disassembly processes emerged after the Second World War to complement concurrent engineering (CE)[70]. *Design for Manufacturing* DfM, as one of the first techniques of design for special purposes, appeared in the 1960s[71]. At that time, General Electric published its first reference book for industry titled *Manufacturing Producibility Handbook*[72]. The publication consolidated industrial know-how relevant to manufacturing in a single work, explaining how to design products effectively. The Handbook highlighted design of products to boost "producibility", that is to say, for producibility. Also mentioned therein are several points related to assembly. As a result, on many occasions, solutions were created that were relevant in terms of manufacturing processes (e.g. instead of designing one complex part, a number of simpler parts were designed, which certainly facilitated their manufacturing; however, the total cost of that solution including the cost of assembly and other processes was much higher than if a single part had been used). At that point it had become clear that the goal should be to simplify the structure of the product in view of reducing assembly costs and the total cost of the product, rather than solely the manufacturing process[73]. Thus, in the late 1970s, DfM was expanded to include the idea of *Design for Assembly* - DfA. Consideration was given to the complexity of all guidelines to support the process of design for assembly. Note that the concept of design for manufacturing has continued to evolve, with manufacturing aspects being to some extent narrowed down towards specialization, e.g. design for robotic assembly[74], or to take into account selected issues of tool management, the foundations for which were laid down in Poland by Gawlik and Harasymowicz in the 1980s[75].

In 1983, the first edition of Boothroyd and Dewhurst's "*Product Design for Assembly*" was published[76], while in 1986, Hitachi published its first industry guide on how to assess assemblability[77]. From that moment on, certain techniques of design for special purposes have been assigned to the successive phases in the product life cycle giving rise to *Design for*

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[70] Skołud B., *Komputerowo zintegrowane wytwarzanie*, Wydawnictwo Politechniki Śląskiej, Gliwice, 1997, pp. 108-118.

[71] Although research on manufacturability had been done much earlier by Sokolowski (1938), Mitrofanowa (1960), Burbidge (1963), Optiz (1968), which you can read about [in] Deuse J., Konrad B., Bohnen F., *Renaissance of Group Technology: Reducing Variability to Match Lean Production Prerequisites*, Proceedings 7th IFAC Conference on Manufacturing Modelling, Management, and Control International, Federation of Automatic Control, Saint Petersburg, Russia 2013, pp. 998-1003.

[72] *Manufacturing Producibility Handbook,* General Electric Co., Manufacturing Services, Schenectady, New York, 1960.

[73] Boothroyd G., Alting L., *Design for Assembly and Disassembly*, Keynote Paper, CIRP Annals – Manufacturing Technology 41 (2), 1992, p. 625.

[74] Sawik T., *Planowanie i sterowanie produkcji w elastycznych systemach montażowych,* Wydawnictwo Naukowo Techniczne, Warszawa, 1996, pp. 29-32.

[75] Gawlik J., Harasymowicz J., *Wybrane zagadnienia z organizacji gospodarki narzędziowej*, Politechnika Krakowska, Kraków, 1984, pp. 215-228.

[76] Boothroyd G., Dewhurst P., *Product Design and Assembly, Designer Handbook …*, op. cit., 1983.

[77] Ohashi T., Iwata M., Arimoto S., Miyakawa S., *Extended Assemblability Evaluation Method (AEM)*, JSME International Journal Series C Mechanical Systems, Machine Elements and Manufacturing, Vol. 45, Is. 2, 2002, pp. 568-569.

Maintainability – DfMa[78], *Design for Disassembly* – DfDa[79], *Design for Sustainability* – DfS[80], *Design for Obsolescence* – DfO[81], *Design for Network* – DfN which addresses product life cycle issues within network structures, *Design for Recycling* – DfR[82], *Design for Quality* – DfQ[83], *Design for Service* – DfS[84], *Design for Testability* – DfT[85], *Design for Environment* – DfE[86], *Design for Flexibility* – DfF[87], *Design for Cost* – DfC[88], *Design for Variety* - DfV[89], and finally, *Design for Life Cycle* – DfLC[90]. Also worth reporting are *Design for Delivery* – DfD[91], *Design for Logistics* – DfL[92] as well as *Design for Supply Chain* – DfSC[93], by many authors considered to be identical concepts[94].

DfX therefore represents a universal and multidisciplinary approach to the product design process, with the overarching goal of defining design concepts that take the largest possible range of needs of all project stakeholders into consideration in an optimal and balanced way. Note that the diverse catalogue of areas and issues addressed by DfX is by no means closed. It can be extended, for example, to include design for ageing populations [95], food safety[96], knowledge etc., however, from the perspective of the whole concept, each of these areas would generate a distinct combination of determinants. If the presented DfX elements were to be considered in the context of the final customer gain, they could be divided into those that serve the manufacturer, those that are mainly oriented towards the customer, and those that are mutually beneficial – both for the enterprise and for the customer – Table 2.

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[78]Standard developed by NASA. Retrieved May 17, 2018, from https://msis.jsc.nasa.gov/sections/section12.htm

[79] Kuo T., *Disassembly sequence and cost analysis for electromechnical products,* Robotics and Computer-integrated Manufacturing, Vol. 16, No. 1, 2000, pp. 43-54.

[80] Sandborn P., *Designing engineering systems for sustainability,* [in:] Misra K. (ed.), *Handbook of Performability Engineering,* Springer, London, 2008.

[81] Sandborn P., *Software obsolesce – complicating the part and technology obsolescence management problem,* IEEE Transaction on Components and Packaging Technologies, Vol. 20, No. 4, 2007, pp. 886-888.

[82] Becker J.M.J., Wits W.W. *A Template for Design for eXcellence (DfX) Methods*, [in:] Abramovici M., Stark R. (eds.), *Smart Product Engineering. Lecture Notes in Production Engineering ...*, op. cit., pp. 34-35.

[83]Booker J.D., *Industrial Practice in Designing for Quality,* International Journal of Quality & Reliability Management, Vol. 20, No. 3, 2003, pp. 288-203.

[84] Subramani A., Dewhurst P., *Efficient design for Service Consideration*, Manufacturing Review, Vol. 6, No. 1, 1993, pp. 40-47.

[85] Williams T.W., Parker K.P., *Design for Testability: a Survey,* Proceedings of the IEEE, Vol. 71, No. 1, 1983, pp. 98-112.

[86] Fiksel J.R., *Design for Environment: Creating Eco-Efficient Product and processes*, McGraw-Hill, New York, 1996.

[87] Maltzman R., Rembis K., Donisis M., Farley M., Sanchez R., Ho A., *Design for Networks – ultimate design for „X”*, Bell Labs Technical Journal, Vol. 9, No. 4, 2005, pp. 5-23.

[88] Lehto J., Harkonen J., Haapsasalo H., Belt P., Mottonen M., Kuvaja P., *Benefits of DfX in Requirements Engineering,* Technology and Investment, Vol. 2, No. 1, 2011, pp. 27-37.

[89] Martin M., Ishii K., *Design for Variety: methodology for understanding the costs of product architectures,* Proceedings of The ASME Design Engineering Technical Conferences and Computers in Engineering Conference, Baltimore, 1996.

[90] Keoleian G., *Application of life cycle assessment to design*, Journal of Cleaner Production, Vol. 1, No. 3-4, 1993, pp. 143-149.

[91] Kaski T., Heikkila J., *Measuring Product Structures to Improve Demand-Supply Chain Efficiency,* International Journal of Technology Management, Vol. 23, No. 6, 2002, pp. 578-598.

[92] Mather H., *Design for Logistics (DfL) – the next challenge for designers …,* op. cit., pp. 7-9.

[93] Garg A., *An application of designing products and processes for supply chain management,* IIE Transactions, Vol. 31, No. 5, 1999, pp. 417-429.

[94] Lamothe J., Hadj-Hamou K., Aldanondo M., *An optimization model for selecting a product family and designing its supply chain,* International Journal of Operational Research, Vol. 169, No. 3, 2006, pp. 1030-1047.

[95] Polak-Sopińska, A., *Ergonomics as an age management tool in the era of industry 4.0.*, [in:] Lachiewicz S., Flaszewska S. (eds.), *Wybrane problemy zarządzania rozwojem organizacji w przemyśle 4.0.*, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, pp. 109-130.

[96] Walaszczyk A., Galińska B., *Food Origin Traceability from a Consumer's Perspective,* Sustainability, Vol. 12 (5), 2020.

Table 2. Main beneficiaries of the elements of Design for eXcellence

Design for eXcellence		
Enterprise	**Enterprise and Customer**	**Customer**
DfM – Manufacturing	DfS – Sustainability	DfMa – Maintainability
DfA – Assembly	DfR – Recycling	DfO – Obsolescence
DfDa-DfD – Disassembly	DfE – Environment	DfF – Flexibility
DfT – Testability	DfQ – Quality	DfV – Variety
DfC – Cost	DfL – Logistics	DfD – Delivery
DfSC – Supply chain	DfN – Network	DfLC – Life cycle
DfLC – Life cycle		DfSv – Service
DfSv – Service		

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 36.

Table 2 may raise some questions as to the clear-cut assignment of the respective design methods since the areas they are to support are often multidimensional. It would nevertheless appear that bilateral benefits from design for sustainability, the environment, and recycling could be captured within the recently developed concept of Design for Circular Economy[97]. The issue of design for quality is not controversial as far as mutual benefits are concerned (quality is equally important for production processes as it is for subsequent use of the product). Somewhat more debatable are design for life cycle and design for service mainly because even though the two beneficiaries are keenly interested in reaping benefits, there appears to be a divergence of interests. Often, after-sales services are an additional source of revenue for companies, whereas for the customer they are a cost. Finally, there are three items that are basically related to logistics, namely design for delivery (one of the logistic phases – distribution), design for the supply chain (which actually means logistics as a whole – all of its phases and all of its processes), and Design for Logistics, which incorporates the two previous models.

Chiu and Okudan[98] conducted a fairly broad literature review regarding the DfX concept and made an attempt to give the concept a structure by organizing it into 5 fundamental categories based on the nature of the presented tools. Taking into account the level of detail, they identified: guidelines, checklists, metrics, mathematical models, and methods. Guidelines provide directions to be followed and indicate objectives to be pursued. Checklists include opinions, calculations, and a set of closed questions concerning the design – they enable

[97] E.g. Lewandowski M., *Designing the Business Models for Circular Economy---Towards the Conceptual Framework,* Sustainability (2071-1050), 8, 2016, pp. 1-28.
[98] Chiu MC., Okudan G., *Investigation of the applicability of Design for X tools during design concept evolution: a literature review*, International Journal of Product Development, Vol. 13, No. 2, 2011, pp.152-153.

identification of a set of conditions that should be addressed during the implementation of some projects. Metrics, which may often combine guidelines and checklists, are used to quantify product compliance with the design specifications. Mathematical models verify equations and formulas applied in the design process, thus enabling assessment of the efficiency and effectiveness of design work. A method consists in a systematic, clear, and procedural description of previous activities, neither assigning design tasks to specific methods nor defining the order of task execution[99].

The presented model and the described methods and techniques appear only to outline challenges faced by design in the 21st century. Because in the discussed model, apart from traditional aspects related to design, such as economic, humanistic, or marketing factors, there are also those that draw attention to the need to consider manufacturing in design processes. Although one may recognize that Design for Manufacturing, which many authors refer to as manufacturability[100], with the authors of this publication favoring the former term, includes taking into consideration factors relevant to logistics, it may seem an overly superficial approach to the problem as it only involves one of the logistical phases – production logistics. However, since manufacturing in itself is strongly tied to production logistics, it should be useful to present the concept of design for manufacturing and to define its premises.

The economics of manufacturing finished goods unrelentingly proves that two of the key factors in the manufacturing process are time and cost. More and more commonly, however, it has been noted that the very construct of the product itself, which is related to its design, frequently precludes achievement of the intended results. It is therefore logical to draw attention to the fact that already in the product design process, specific features of the subsequent manufacturing or assembly processes must be taken into account to enable the production process to be carried out more efficiently. Estimated data from across the industry indicating that approximately 75% to 90% of total manufacturing costs are determined by product design[101] provide support to that claim. Therefore, organizations are forced to deal with factors associated with product manufacturing as early as during the process of its design. The concept of design for manufacturing and design for assembly (DfA) have been present in the world literature.

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[99] Becker J.M.J., Wits W.W., *A template for Design for eXcellence (DfX) Methods*, [in:] Abramovici M., Stark R. (eds.), *Smart Product Engineering…*, op. cit., pp. 34-35.
[100] e.g. Matuszek J., Seneta T., *Ocena technologiczności konstrukcji w procesach montażu wyrobów metodą Lucas DFA,* Mechanik No. 7, 2017, pp. 523-525.
[101] Fabrycky W.J., *Designing for the Life-cycle,* Mechanical Engineering, 1987, pp.72-74; Daetz D., *The effect of product design on product quality and product cost,* Quality Progress, 1987, pp. 40-44.

The term DfM was defined by Stoll in 1990[102]. Conceptually, it is framed as a comprehensive approach to the process of design, applying certain methods, techniques as well as attitudes, whereby the product is designed with a view to optimizing manufacturing costs and achieving optimal parameters in terms of quality, life cycle support, ease of maintenance, with optimal reliability and with optimal consideration of the principles of recycling. Two years earlier, the same author specified primary objectives for design for manufacturing and summarized them with the following three points:

1) establish a product concept that by default is easy to implement in a given production environment;
2) focus on designing product components that are easy to manufacture and assemble;
3) integrate the process of manufacturing design with the process of product design to ensure the best possible fulfillment of customer needs and requirements[103].

Yu, Krizan and Ishii are correct in their claim[104] that DfM rests on the premise that the cost and quality of the product are inherent in product design. The methodology of the concept under discussion anticipates active pursuit of integrating value resulting from the product life cycle as early as during its design and development. In the opinion of these authors, the DfM method enables engineers, provided they follow a consistent methodology, to reduce product design and development time, reduce production costs, and limit defects in finished goods. It concentrates on certain manufacturing processes, e.g. machining, forming, and assembly, with the aim of incorporating in the initial phases of product design ideas that preclude production problems and significantly facilitate production processes. In the same study, the authors very interestingly present how design knowledge that allows for identification of available engineering solutions is acquirable from the already existing databases. Ishii, Adler, and Barkman[105] call such analysis *Design Compatibility Analysis* – DCA. DCA is founded on the premise that in different phases of the design process, designers need different, rather than always the same, kind of information. At a very early stage of the design process, engineers expect to gain more qualitative information on the compatibility between specifications and processes of the pending design, compared to designs already implemented, instead of quantitative knowledge about product life cycle cost. Depending on the outcome of the comparative analysis (is there a similarity or is there not), either a compatibility-based or a case-

[102] Stoll H.W., *Design for Manufacturing,* Simultaneous Engineering, C.W. Allen edit, SME Press, 1990, pp. 23-29.
[103] Stoll H.W., *Design for Manufacturing*, Toll and Manufacturing Engineers Handbook, Vol. 5, SME Press, 1988, pp. 13.1-13.32.
[104] Yu J.C., Krizan S., Ishii K., *Computer Aided Design for Manufacturing Process Selection,* Journal of Intelligent Manufacturing Systems, ASME, 1980, p. 199.
[105] Ishii K., Adler R., Barkan P., *Application of design compatibility analysis to simultaneous engineering*, Artificial Intelligence in Engineering Design and Manufacturing, AI EDAM, Vol. 2, Issue 1, 1988, pp. 53-65.

based approach may be used[106]. As the design process proceeds, designers can use more quantitative forms of similarity (compatibility) information. The selected representative design then becomes a database of qualitative information on the various associated costs, which leads to the ranking of processes. This distinction is important inasmuch as it can serve as an important feature of the concept of Design for Logistics.

The aforementioned Stoll[107] stated that design for manufacturing should be based on a twostage process. The first stage is related to the fact that each functional requirement and limitation for a product, device or a system ought to be considered through the lens of many independent aspects, attributes, properties and components in the design process. Practical here may be a hierarchical structure of functional requirements, starting with those that are critical down to those least relevant. The second stage is related to the continuation of design efforts to incorporate functional requirements into the entire design decision making process. Useful here may be two axioms formalized by Yasuhara and Suh[108] that take into account a broader spectrum of functional determinants, namely:

1) in a good design functional independence is retained;
2) of the designs that satisfy axiom 1, the best design is the one with the minimum information content.

The DfM also rests on some fundamental precepts. Chang, Wysk, and Wang[109] propose a group of guiding principles that help designers reduce production costs, including the following ten:

1) reducing the number of elements in the finished product;
2) maximizing modularity;
3) maximizing the number of standardized details in the finished product;
4) focusing on designing multifunctional parts and components;
5) concentrating on designing parts and components whose functions may be used in a wide variety of finished products;
6) focusing on designing with materials that are easy to produce;
7) avoiding having a variety of fasteners (threaded, push-fit, requiring specialized tools);
8) minimizing product repositioning during product assembly;
9) maximizing compliance (yielding and vulnerability to production processes);
10) minimize handling.

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[106] Yu J.C., Krizan Ishii K., *Computer Aided Design for Manufacturing Process Selection …,* op. cit., pp. 200-201.
[107] Stoll H.W., *Design for Manufacturing,* Simultaneous Engineering …, op. cit., pp. 23-29.
[108] Yasuhara, M. Suh N.P., *A Quantitative Analysis of Design Based on Axiomatic Approach,* Computer Application in Manufacturing Systems, ASME, 1980, pp. 1-20.
[109] Chang T-Ch., Wysk R., Wang H-P., *Computer-Aided Manufacturing*, 3rd Edition, Pearson Education, New York, 2005, pp. 596-598.

Kuo and Hong-Chao Zhang[110] list directions and goals of Design for Manufacturing and conclude that the process of design of the product or product parts should:

1) limit the number of components used in the design;
2) consider the principles of modular design;
3) minimize the need for changing parts used in the designed product;
4) minimize use of connecting elements;
5) take into account their multi-functionality;
6) address their multiuse in other solutions;
7) take into consideration the ease of their production;
8) follow the idea of design for assembly to minimize assembly defects, and apply top-down approach to assembly (from the 'structural frame' to the finishing elements);
9) maximize compliance of the designed pieces to facilitate assembly;
10) minimize handling and the need for additional descriptions and instruction manuals;
11) include evaluation of assembly methods;
12) eliminate and simplify product adjustment;
13) avoid flexible pieces.

The presented principles share many common features, such as minimizing the number of elements in the finished product, applying the concept of modularity of parts as well as using multifunctional components or parts. The differences in both approaches appear to be rather minor and, in general, tend to pertain to the level of detail provided for design for assembly.

The concept of modularity referred to by the authors is defined as a special form of design whose primary goal is to create elements which are highly independent of one another but which nevertheless have a common, standardized interface specification linking them into one integrated product or a system. Each of the modules therefore serves a range of certain functions in the product as a whole, the combination of which creates the final effect in the product[111].

The concept of product Design for Assembly has also been introduced. Unquestionably, the concept draws on the experience from the preceding approach (DfM), however, it moves a step further. It enables designers to gain insight into determinants and specificity of assembly[112]. DfA includes several instruments to identify areas that should be addressed in the process of design for assembly, among them the assemblability evaluation method (AEM) put

[110] Kuo T.C., Hong-Chao Zhang, *Design for Manufacturability and Design for "X": Concepts, Application, and Perspectives,* Proceedings International Electronics Manufacturing Technology Symposium, IEEE/CPMT, Computers & Industrial Engineering Volume 41, Issue 3, 2001, pp. 447-448.

[111] Sanchez R., Mahoney J.T., *Modularity, flexibility, and knowledge management in product and organization design,* Strategic Management Journal, Vol. 17 (Winter Special Issue), 1996, p. 64.

[112] Fazio T., Rhee Whitney D., *Design-Specific Approach to Design for Assembly (DFA) for Complex Mechanical Assemblies*, IEEE transactions on robotics and automation, Vol. 15, No. 5, 1999, p. 869.

forward by Hitachi[113], and its more elaborate version, the extended assemblability evaluation method[114], Fujitsu's productivity evaluation system[115], as well as the popular Boothroyd-Dewhurst method[116]. The concept is based on the principle "one part, one motion", first used by Hitachi in the 1980s and can be summarized with three main processes: manual assembly, designation of a particular fragment of assembly for automation, and flexible assembly. Advanced databases and computer techniques are often used in DfA to assess assembly time and on this basis determine the cost of designed parts and manufacturing costs down the line.

The aforementioned Boothroyd, Dewhurs, and Knight, formulated the following four key principles necessary to implement assembly for design:

1) providing designers with tools (mainly IT) that would be able to detect elements of the complexity of the product that impact on its assembly;
2) creating solutions for product simplification, aimed at minimizing assembly cost;
3) sharing knowledge between designers and design teams on the best solutions to support the assembly process;
4) building a database for designers, showing standardized times and cost of assembly operations, for various design scenarios and production process conditions[117].

The same authors defined basic principles of design to facilitate the handling of parts and the process of assembly in terms of inserting parts and fastening them. The principles defined by these authors include the following[118]:

- maximizing the number of parts with perfect rotational and longitudinal symmetry (if this cannot be achieved then parts should be designed that are symmetrical to the greatest possible extent);
- providing solutions in designed parts to prevent blocking, nesting and other situations hindering efficient assembly;
- ensuring that the designed parts can be stacked for storage, if necessary;
- avoiding design and use of parts whose features and characteristics create a risk of joining or tangling;
- avoiding design and use of parts that stick together or are slippery, fragile, flexible, very small, very large or hazardous to the handler;

[113] Miyakawa Shigemura T., *The Hitachi assemblability evaluation method (AEM)*, Proceedings International Conference Manufacturing Systems Environmental -– Looking Toward 21st Century, 1990, pp. 277–-282.
[114] Ohashi T., Iwata M., Arimoto S., Miyakawa S., *Extended Assemblability Evaluation Method (AEM) …*, op. cit., pp. 567-574.
[115] Sakai Y., Miyazawa A., *Fujitsu's Innovation in Manufacturing and Engineering*, Fujitsu Scientific and Technical Journal, Vol. 43, No. 1, 2007, pp. 3-13.
[116] Boothroyd G., Dewhurst P., Knight W., *Product Design for Manufacture and Assembly*, 3rd edition. CRC Press, Boca Raton, 2011.
[117] Ibid., p. 86.
[118] Ibid., pp. 86-92.

- optimizing part and component fasteners to ensure that there is no resistance during assembly;
- using standard parts, tried and tested in the production process (increasing production volume with lower unit cost);
- designing products for assembly along one axis of reference - pyramid assembly, which follows from the principle of ergonomics which says it is best to assemble from the top;
- ensuring auto-positioning of mating parts in the assembly process, and solutions to facilitate insertion;
- using standard fastening solutions in the design process, primarily snap fitting, plastic bending, riveting, and screw fastening;
- designing with a view to avoiding repositioning of the partially completed assembly in the unit.

Each of the listed points clearly refers to the assembly process which is a specific technological process[119]. All the guidelines referred to above appear important from the point of view of the efficiency of the production process, which obviously has a direct impact on costs.

A very interesting continuation of the DfM and DfA theme is the concept of design for variety (DfV) by Martin and Ishii[120]. In the study, the authors concentrated on solutions intended to reduce the effect of product assortment on the total product life cycle cost. They formulated the two key indicators: the Generational Variety Index (GVI) and the Coupling Index (CI). The former is used to indicate the number of redesigned parts in new products. The latter shows the relationships between redesigned elements – the stronger the structural and functional relationships between the components, the more likely it is that a change in one will entail a change in the other. The methodology of design for variety introduced by the authors, which makes use of the two indicators, has made it possible to generate solutions optimizing the number of components and parts in the final product.

The presented literature review clearly shows that designers first attempted to incorporate in the design and development process those elements that are directly related to the production process, and in particular to its limitations (DfM). Later, the concept of Total Quality Management – TQM[121], which at the time developed in Japan owing to Deming, led to the inclusion of further issues, e.g. quality, one of aspect of which is reliability or the possibility of testing and inspection (DfQ, DfR, DfT, DfI). As globalization and mass production intensified,

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[119] Durlik I., *Inżynieria Zarządzania,* Agencja Wydawnicza Placet, Gdańsk 2005, pp. 65-70.
[120] Martin M., Ishii K., *Design for Variety: developing standardized and modularized product platform architectures* …, op. cit., pp. 213-235.
[121] Hamrol A., Zymonik Z., *Zarządzanie jakością,* [in:] Knosala R. (ed.), *Inżynieria produkcji. Kompendium wiedzy …,* op. cit. pp. 565-574.

the problem of assembly lines and assembly processes received greater attention, which resulted in the emergence of the concept of design for assembly (DfA), whereas climate change demanded that consideration be given to environmental and recycling concerns (DfE, DfR). The complexity of the market coupled with higher customer expectations for product personalization required that considerations concerning flexibility (DfF) and diversity (DfV) be brought into the design processes. Other product-specific challenges generated new concepts that were addressed by Design for Excellence (DfX), Design for Cost (DfC), and Design for Life Cycle (DfLC).

Duda[122] pointed out that in the integration of product development phases, an important role is played by the aforementioned methods and systems which facilitate evaluation of a solution as a result of design for excellence. The methodology, as described by DfX, helps to reduce production costs by providing designers with recommendations based on formulated conclusions which they can be implement as early as at the conceptual development stage.

Design and modification of a product (product development) is an interdisciplinary activity which requires understanding and support from all functional departments of the organization. Naturally, modification or improvement – product development – shares many characteristics with design process, both with regard to definition as well as to methodology. Therefore, there is no need to separate it out theoretically. Note, however, that most of the publications on product design and/or development situate the phenomenon in the context of an engineering approach. The phenomenon focuses on product development rather than design from the very beginning.

The 21st-century global market is increasingly experiencing limitations related to the rate of response to customer needs, resulting mainly from the necessity to move raw materials and goods between acquisition, manufacturing, and sales locations, hundreds or thousands of kilometers away from each other. The necessity to raise the degree of product customization, which is a consequence of changes in consumer attitudes, does not improve the situation either. Unquestionably, the high degree of personalization contributes to the shift of the decoupling point - DP, closer to manufacturing sites. Both these key aspects, with advancing globalization, are inextricably linked to logistics and supply chains. Hence the need to further extend scientific research to study Design for Logistics and to clearly establish the relationship between DfL and Design for Supply Chain (DfSC). They naturally complement the concept of Design for Excellence (DfX). Further, although integration of all approaches into one cohesive and

[122] Duda J., Zarządzanie rozwojem wyrobów w ujęciu systemowym …, op. cit., pp. 37-38.

coherent whole appears to be highly challenging, the existing body of research findings concerning DfX should be considered within the DfL concept.

The presented literature review draws attention to many aspects of the design process. It also shows that the essence of the overall design process may involve creation of new products or modification of existing ones. Giving a synthetic summary, one could identify certain underlying assumptions of the design process that should be taken into account in Design for Logistics.

The next section of this book explores the topic of Design for Logistics (DfL) which, based on the literature review, has the potential to be further developed and framed within a somewhat different perspective.

2. DESIGN FOR LOGISTICS

2.1. Definition and assumptions of Design for Logistics

When attempting to formulate the fundamentals of Design for Logistics or Design for Supply Chains, one should first give a brief overview of the relevant literature. Part of the literature review should certainly address logistics and supply chain issues. Note, nonetheless, that these concepts, have been present in the literature for decades.

Taking a methodologically appropriate design (*designing proper*) as a valid approach to the issues of the process of design, one must assume that knowledge from many disciplines will be put to use[123]. For the purposes of this book, it would also be appropriate to combine the knowledge described and to present selected elements that feed into the process of Design for Logistics. Therefore, first of all, attention should be drawn to a short description of logistics itself.

Logistics, in its essence, is a spatio-temporal transformation of goods and services integrated by management processes, for the flow of goods and their related information[124]. The preferable definition of logistics is provided by a commercial organization, the Council of Logistics Management, which describes logistics as "*the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements*"[125]. Note, of course, that this definition fails to refer to a very important element of logistics related to the collection of end-of-use goods from the market, however, for the sake of a preliminary understanding, this definition appears to suffice.

Pfohl provided a meaningful dissection of logistics[126] by distinguishing the following phases of the flow of products and their related information from the point of origin to the point of consumption: procurement, production, distribution, disposal and returns. The same author also defined the main processes that occurred in logistics: transportation, warehousing, packaging, order handling, and inventory management. This distinction in logistics between its phase and functional contexts will represent an important factor delineating the boundaries of Design for Logistics activities.

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[123] Bendkowski J., *Projektowanie procesów i operacji logistycznych – wybrane problemy*, Zeszyty Naukowe Politechniki Śląskiej, Organizacja i Zarządzanie, 101/2017, p. 24.
[124] Ibid., p. 473.
[125] Retrieved February 2, 2018, from https://www.britannica.com/topic/logistics-business#ref528537
[126] Pfohl H., *Systemy logistyczne. Podstawy organizacji i zarządzania*, Instytut Logistyki i Magazynowania, Poznań, 1998, pp. 17-20.

Gołembska, in „Kompendium wiedzy o logistyce", defines the logistics chain as a warehousing and transportation sequence, which is a technological connection via freight routes of storage and transshipment nodes, subject to organizational and financial coordination involving all policies and actions of all stakeholders in the chain[127]. Witkowski, on the other hand, described the supply chain as the interaction of companies and customers in various functional areas through which streams of products, their related information, and finances are transferred[128].

Clearly, providing an adequate definition of supply chain management can hardly be considered a simple task anymore. Certainly, it can be described in terms of the principal management functions executed across the supply chains, however, the authors of the definitions provided in the compendium concentrate on different aspects of the problem, e.g. systems approach to the entire chain, cooperation between the stakeholders in the chain, exchange of information, integration of core business processes, and the decision-making process.[129]. Each definition therefore highlights a different, important context of the supply chain. Nonetheless, it must be stated with objectivity that the crux of all supply chain management is to create a purposeful and organized system of businesses that could effectively and efficiently deliver products to the market to end customers as well as collect end-of-use products from the market and deliver them to appropriate return or disposal sites.

Witkowski[130] proposed the following three main goals for the supply chains:

1) logistic cost-efficiency – optimization of logistic costs by minimizing the costs of flows and storage of products and their related information, while maximizing the quality of customer service;
2) logistic efficiency - associated with minimizing delivery time while maintaining adequate reliability, flexibility and frequency;
3) inventory optimization.

Naturally, these objectives can also be accompanied with comprehensive cooperation of supply chain partners in every dimension and to any extent in order to continually improve it, integration and coordination of material, information, and financial streams, optimization of added value[131].

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[127] Gołembska E. (ed.), *Kompendium wiedzy o logistyce …*, op. cit., p. 19.
[128] Witkowski J., *Zarządzanie łańcuchem dostaw. Koncepcje. Procedury. Doświadczenie …,* op. cit., p. 19.
[129] Knosala R. (ed.), *Inżynieria produkcji. Kompendium wiedzy ...,* op. cit., p. 520.
[130] Witkowski J., *Zarządzanie łańcuchem dostaw. Koncepcje. Procedury. Doświadczenie …,* op. cit., p. 30.
[131] Szymonik A., Zielecki W., *Logistyka. Zarządzanie Łańcuchami Dostaw,* [in:] Knosala R. (ed.), *Inżynieria produkcji. Kompendium wiedzy ...,* op. cit., p. 519.

The presented issues provide the groundwork for a discussion about the concepts of Design for Logistics and Design for Supply Chain. As DfL and DfSC appear conceptually similar, a review of the literature relating to both was undertaken. As a result, it was found that among the content searched for both concepts, there appeared mere visions of selected concepts either derived from the analysis of specific manufacturing problems or selectively addressing the problem in question. It is therefore difficult to say conclusively how many DfL concepts have appeared in the body of literature. If the criterion of a holistic description is assumed, then Mather[132] and Dowlatshahi[133] should be considered the creators of DfL.

The first theoretical findings related to the DfL concept appeared in the publication by a group of managers: Foo, Clancy, Lindemunder, Kinney[134], who in 1990 introduced the concept of Design for Material Logistics (DfML). In their work, the authors defined the primary aspects that should be considered in the process of product design in order to achieve a product that was perfect from the standpoint of material logistics. Their model envisaged:

- minimization of the number of parts or components;
- making use of standard or a small set of special (custom) parts and components ("preferred" parts);
- limiting the number of end item configurations (an end item is a product that is sold as a complementary item or a repair part or any item specified in the customer order or a sales forecast);
- making use of product modularity and product structure (Bill of Materials – BOM).

The authors concluded based on the example discussed in their article that the first three recommendations for design for material logistics had been properly applied and there was no need for redesigning. As for the third issue, although limiting product configurations brings financial advantages, corporate strategies mandate that products be adapted to customer requirements. Therefore, in the economic reality, offering only a limited set of configurations, for the presented example, was not feasible. The last aspect, i.e. product modularity and product structure (Bill of Materials – BOM), is the most critical issue. The authors further pointed out that limiting the possibility of complementing the final product by the customer (limiting customization) was a factor that supported the DfML approach.

[132] Mather H., *Design for Logistics (DfL) – the next challenge for designers …*, op. cit., pp. 7-9.
[133] Dowlatshahi S., *The role of logistics in concurrent engineering …*, op. cit., pp. 189-199.
[134] Foo G., Clancy J.P., Lindemunder Ch. R., Kinney L. E., *Design for material logistics*, AT&T Technical Journal, May-June 1990, pp. 61-76.

Design for Logistics as such appeared in 1992, when Mather, drawing on his previous publications[135], was the first to define the concept as an immediate response to the need of a customer as soon as it arises – "*… to delight the customer with a product when needed*"[136]. He rightly argued that many of the logistic issues arising from product design cannot be compensated for by the work of marketing departments or by manufacturing techniques. In the article cited above, he listed examples of activities related to launching a consumer electronics product on the market, pinpointing an entire range of flaws in the process of design and their ensuing consequences. As a key feature of the concept he proposed, Mather introduced the P/D ratio, where the letter "P" stands for the total lead time from sourcing raw materials to processing them into finished goods, whereas the letter "D" stands for the customer lead time, that is the time from receiving the order from the customer to delivering the product to the customer. According to Mather, for a majority of companies, the ratio is greater than one, which is compensated by pursuing a make-to-stock production strategy firmly anchored in forecasting processes. This follows from where the *Decoupling Point* – DP is sited. The decoupling point may be understood as a specific point in the flow of materials where a product binds to a specific (one might add, personalized) customer order[137]. If the make-to-stock production strategy is pursued, the decoupling point will be located directly in the warehouse. If the assemble-to-order strategy is implemented, it will be located on the production floor, and if the engineer-to-order strategy is applied, the decoupling point will be sited in the raw materials or the in-process inventory zone. Each of the described solutions is linked to the design of the product. Accordingly, Mather argued that often the only possible way to optimize logistic processes would be to redesign the product to satisfy logistic requirements. The author concludes expounding his ideas with the statement that for the DfL concept to be realized it is necessary to strive for:

- a maximum possible number of standard components or modules in the process of product manufacturing;
- deferment of any kind of product personalization – it should take place as late in the order fulfillment process as possible.

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[135] Mather H., *Design, Bills of Materials, and Forecasting-the Inseparable Threesome*, Production and Inventory Management Journal, Vo1. 2 (1), 1986, pp. 90-107.
[136] Mather H., *Design for Logistics (DfL) – the next challenge for designers …*, op. cit., pp. 7-9.
[137] Olhager J., *The Role of Decoupling Points in Value Chain Management*, [in:] Jodlbauer H., Olhager J., Schonberger R. J. (eds.), Modelling Value, Contributions to Management Science, Springer-Verlag Berlin Heidelberg 2012, p. 37.

Mather summarized the overall approach by stating that DfL (termed in the article design for world-class competition) was turning into a major challenge for designers (Design for Logistics and logistically efficient products associated with DfL should become an immanent part of Total Logistics Management – TLM[138]). The relevance and significance of the design process, as well as the actual design, should be defined as a baseline perfectly tuned to each type of business activity.

Effective product design cuts through many functional areas of the organization while focusing on making sure that all the attributes and qualities that the product will have to meet in the market have been incorporated in it. DfL should therefore address considerations related to marketing, manufacturing, procurement (purchasing), quality control, finance, as well as packaging, distribution, transport, plant location, materials management, forecasting, order handling, warehousing, the environment, sales, and scheduling. It is clear by this point that Mather successfully applied the DfX concept to design. Certainly, design efforts should converge to create a product that combines a number of different considerations, although it can be very difficult at times[139].

Having thought about effective engineering design, Dowlatshahi introduced a DfL model consisting of specific modules, which he believes[140] to be the resultant of engineering design of a product (e.g. functional requirements and product profile, physical configuration, structural analysis, selection of parts, determination of the degree of standardization, technical and economic feasibility studies, etc.) and typical logistic determinants (issues related to operational requirements, design of a logistic system, integrated logistics support, supply chain management, etc.) – Figure 3.

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[138] Bielecki M., Galińska B., *The concept and principles of Total Logistics Management in a manufacturing company,* Proceedings of the 17th International Scientific Conference Business Logistics in Modern Management, Faculty of Economics in Osijek, Osijek, Croatia, 2017, pp. 93-107.
[139] Mather H., *Design for Logistics (DfL) – the next challenge for designers …*, op. cit., pp. 7-9.
[140] Dowlatshahi S., *The role of logistics in concurrent engineering …*, op. cit., pp. 189-199.

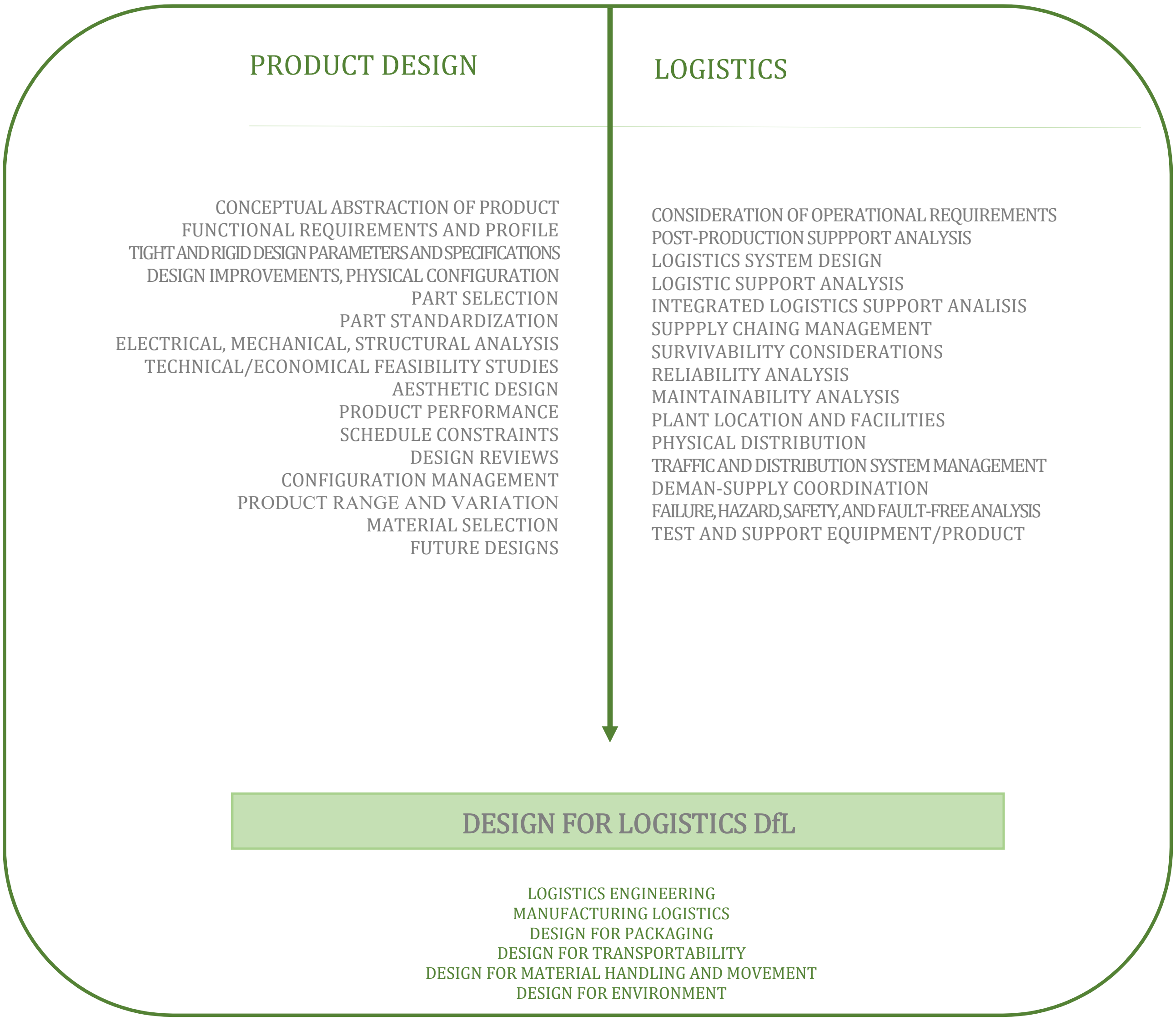

Figure 3. Dowlatshahi's model of Design for Logistics (DfL)
Source: compiled by the authors based on Dowlatshahi S., The role of logistics in concurrent engineering, International Journal of Production Economics, vol. 44, 1996, p. 192.

The main DfL modules include[141] :

- logistics engineering – IL (construed as a part of logistics that deals with product and system support throughout the life-cycle and centered on the process of design where logistic constraints – size, weight, reliability, safety, cost, manufacturability, etc. – should be taken into account in the final configuration of the product);
- production logistics – LP;
- *Design for Packaging* – DfP;

[141] Dowlatshahi S., *The role of logistics in concurrent engineering* ..., op. cit., p. 192.

- *Design for Transportability* – DfT;
- *Design for Material Handling and Movement* – DfMH;
- *Design for Environment* – DfE.

Despite having distinguished the six DfL modules, Dowlatshahi incorporated only four modules into the integrated logistics system (Figure 4). He disregarded design for environment and design for handling and movement of goods (which he wrote more extensively about in his previous work[142]). Design for environment was deemed to be too broad and distinct an area of design.

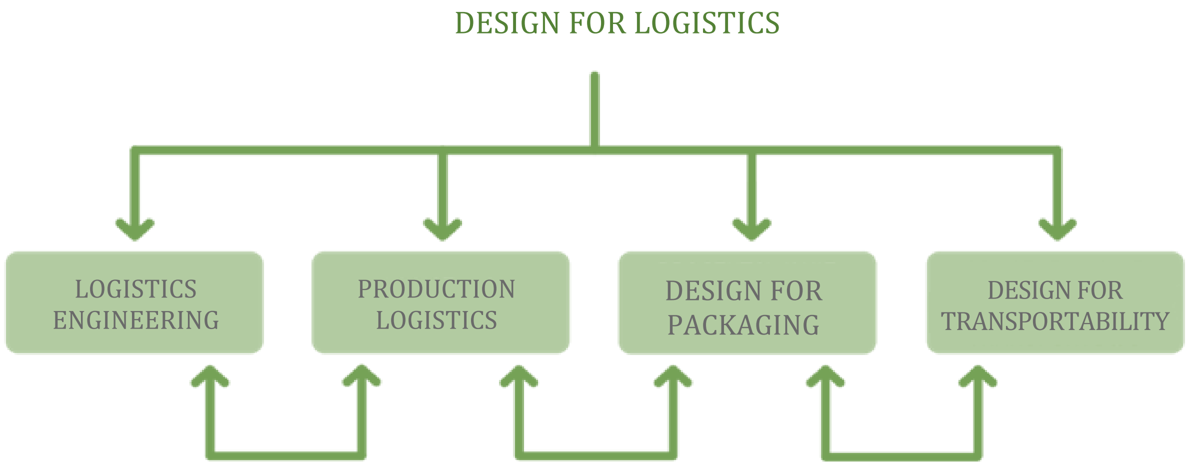

Figure 4. Dowlatshahi's model of integrated logistics system
Source: compiled by the authors based on Dowlatshahi S., The role of logistics in concurrent engineering, International Journal of Production Economics, vol. 44, 1996, p. 192.

Further on, Dowlatshahi hierarchically deconstructed the model of the integrated logistics system in the context of Design for Logistics, detailing elements of the DfL modules listed in Figure 4. Based on that, he singled out the following items of the DfL modules – Figure 5.

[142] Dowlatshahi S., *A modelling approach to design of integrated facilities*, International Journal of Production Research Vol. 32, Is. 6, 1994.

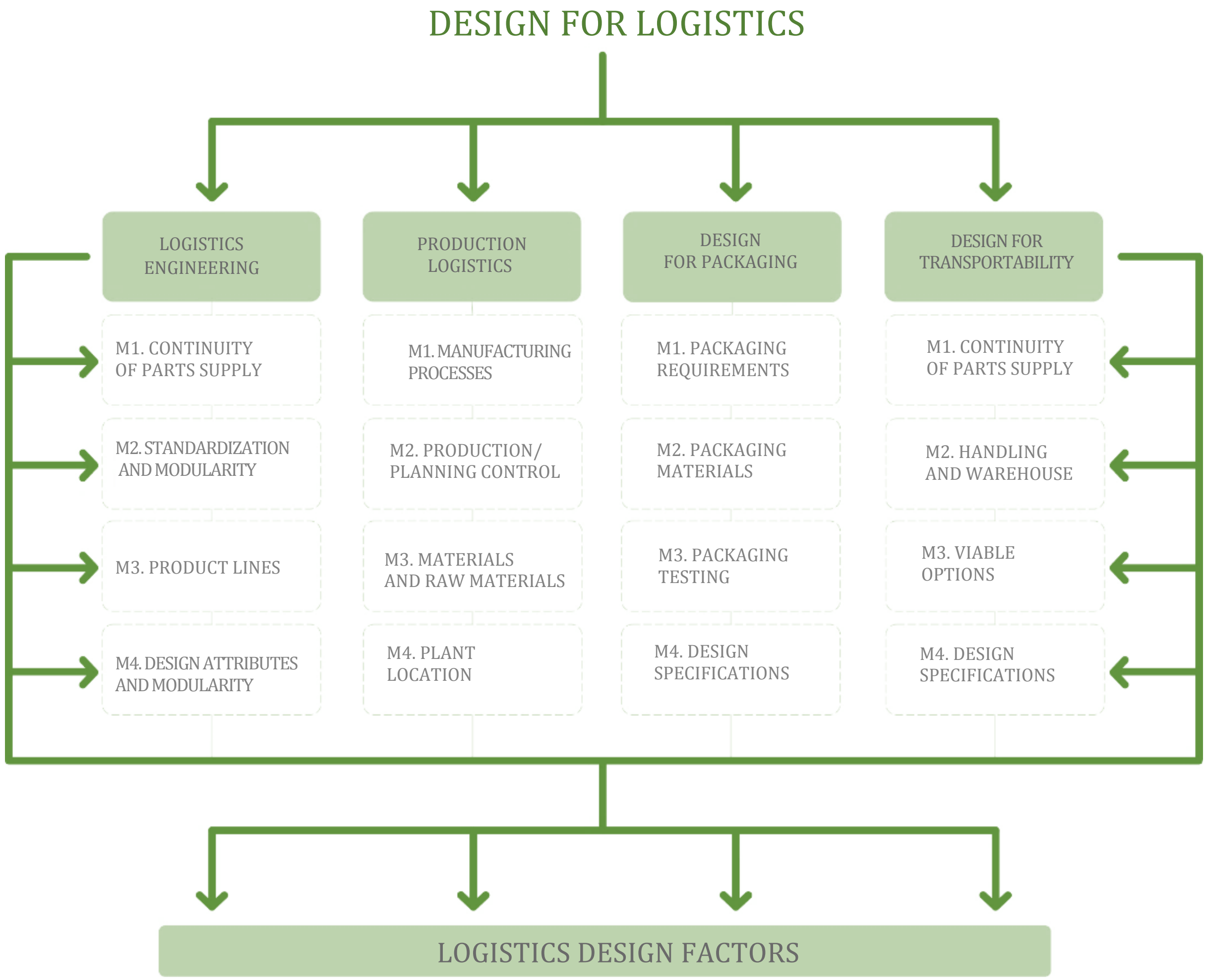

Figure 5. Dowlatshahi's hierarchical deconstruction of Design for Logistics
Source: compiled by the authors based on Dowlatshahi S., The role of logistics in concurrent engineering, International Journal of Production Economics, vol. 44, 1996, p. 193.

As regards logistics engineering, according to Dowlatshahi[143] it includes:

- *Design for supportability* – taking into account in the design process of products and parts the requirements concerning their subsequent distribution through the logistics system – **continuity of the supply of parts**);
- *Design for manufacturability* – product parts should be designed to use as many standard elements as possible, while minimizing the number of parts and using interchangeable parts – **standardization and modularity**);
- product assortment (analysis and evaluation of current product lines – **product mix**);
- **design idiosyncrasies and modularity** (to define feasible – realistic – qualitative and quantitative boundary conditions).

[143] Dowlatshahi S., *The role of logistics in concurrent engineering…*, op. cit., pp. 181-199.

Within the scope of production logistics, Dowlatshahi outlined the following aspects:

- **manufacturing processes** (taking into account and relating the particularities of manufacturing processes – reduction of set-up time, predictability, stability of production cycles, etc. – to solutions implemented in the product which integrate logistic considerations);
- **planning and production control** (taking into account the length of production runs and their impact on logistics as well as the influence of production schedules and other elements related to manufacturing should become an interface for identifying cooperative solutions between production and logistics departments);
- **use of adequate materials and raw materials** (aimed at minimization of the total cost of materials management and creating products that are compact and lightweight);
- **plant location** (impacting on the cost of transportation in the areas of supply and distribution, the speed of reaction to market developments, and also the reliability of deliveries).

As regards design for packaging, Dowlatshahi introduced the following points:

- **functional packaging requirements** (related to reconciling many spheres of the organization activity such as marketing, manufacturing, and logistics; packaging becomes an excellent opportunity to combine many functional requirements of the organization);
- **packaging materials** (both in terms of their internal structure as well as the number of packaging options used);
- **packaging testing** (for shock exposure, fragility, vibrations);
- **packaging design features –** design guidelines (limiting the influence of internal factors, the total cost of the packaging process, and considering both internal and external constraints and requirements).

In the last module, related to design for transportability, the following elements were presented[144]:

- determinants of transportation processes (business aspects of selecting transportation options) – **continuity of the supply of parts**;
- shipping, warehousing, and handling requirements (close linkage between logistics and design as regards availability, selection, and choice of logistics infrastructure) – **handling and storage**;

[144] Dowlatshahi S., *The role of logistics in concurrent engineering…*, op. cit., pp. 181-199.

- requirements related to transportability (identified design features facilitating transportation processes, e.g. physical characteristics and properties, dynamic, environmental, and related to different kinds of risk) – **possible options**;
- criteria for design for transportability (allowing for and minimizing the average delivery time and the variability of delivery time) – **design guidelines**.

The modules and their elements discussed by Dowlatshashi embedded within the DfL structure appear to be somewhat chaotic, which results from including too many factors related to logistics, starting with logistic processes classified by phase and ending with the consideration of logistics systems. Furthermore, the extent to which various DfX concepts are interwoven (e.g. design for environment) as well as a lack of a common logical denominator are the main problem areas in the presented model and require elaboration.

Koike, Blanco, and Penz[145] took a slightly different approach to the topic of DfL. They proposed a concept of collaboration between designers and logisticians in the design process. In the opinion of these authors, the guidelines for DfL designers could be brought down to cost reduction through concurrent engineering. Accordingly, they focused their attention on minimizing the number of reference parts, tailoring packaging, and streamlining logistic processes[146]. The authors also provided guidelines for a model of a logistic profile that supported collaboration between designers and logisticians and was based on the following three principal factors: variables, profile drivers, and profile chart. Regrettably, the study presented by the authors focused on the process character of design, merely pointing out where in the process of product design should logistic specifications be incorporated.

Also Hau L. Lee[147], of the Stanford Graduate School of Business, contributed to the development of Design for Logistics understood as a set of concepts, principles, rules, guidelines, etc., including an approach to product and design that supports effective achievement of the flow of goods and information. He formulated the following three primary components of the conceptual framework:

1) cost-effective packaging and transportation (emphasis was placed on the need for such a design of the product and packaging that would facilitate transportation processes while ensuring product safety, at which point attention was drawn to the context of estimating

[145] Koike T., Blanco E., Penz B., *Logistic profile: a new concept for interfacing designers and logisticians in concurrent engineering environment*, Proceedings International Conference on Engineering Design, 2005 – https://www.designsociety.org/publication/22907/LOGISTIC+PROFILE%3A+A+NEW+CONCEPT+FOR+INTERFACING+DESIGNERS+AND+LOGISTICIANS+IN+CONCURRENT+ENGINEERING+ENVIRONMENT

[146] Koike T., Blanco E., Penz B., *Logistic profile: a new ….*, op. cit., p. 2.

[147] Li Chen, Hau L. Lee, *Sourcing Under Supplier Responsibility Risk: The Effects of Certification, Audit, and Contingency Payment,* Management Science, Vol. 63, Issue 9, 2017, pp. 2795-2812; Hau L. Lee, Schmidt G., *Using Value Chains to Enhance Innovation*, Production & Operations Management. Vol. 26, Issue 4, 2017, pp. 617-632; Hau L. Lee, *The Triple-A Supply Chain*, Harvard Business Review, October, 2004.

the overall cost of manufacturing and distribution as it often revealed that a sturdier product housing/casing, regardless of increasing the cost of a part or a product, could ultimately turn out to be more cost-effective because overall logistic costs would be reduced; the need for solutions supporting logistic operations was also stressed – easy packing, repacking, tracking, etc., and for solutions supporting the creation or exploitation of the supply chains);

2) process concurrency and parallelism (at this point, the author calls for modifying processes so that they could take place in parallel and concurrently – so that they could be performed at the same time, which would shorten production cycles, limit work-in-progress inventory, and reduce warehousing costs due to improved forecasting and cutting down safety stock.);

3) standardization (taking advantage of economies of scale and using items that can be used in many instances and many times; standardization is referred to within the four contexts: sub-assemblies and parts – using the same parts or sub-assemblies in many different products; processes – standardization of production processes to delay eventual personalization of the product; products – taking advantage of substitutability, downward substitution, which, if there is a shortage of a particular product, makes it possible to offer a similar one, although from a different segment; delivery – using standard infrastructure solutions throughout the logistics process for a wide range of products).

Analysis of the proposed concept allows one to notice, as was the case with Dowlatshahi, an absence of any structural arrangement of the discussed concepts. Both the product, the infrastructure as well as production processes are referred to, which is conceptually akin to the previously discussed design for manufacturing and design for assembly. By following Hau Lee's publications, one can see clearly that his research interests tend to revolve around supply chain management, value chain innovation, and delivery rather than design issues. The set of guidelines provided by him, identified within the framework of Design for Logistics, may well arise from that fact.

The review of literature that has been conducted demonstrates clearly that there is a variety of approaches to Design for Logistics (DfL). As much as anchoring DfL within the DfX conceptual framework appears natural, as a complementary element, DfL in and of itself requires structuring and fine-tuning. The reason for this is the multifacetedness and interdisciplinarity of the entire topic, and therefore, the necessity to find common denominators which would help identify related areas. Since environmental concerns were irrelevant at the time when the approaches analyzed thus far were put forward, the need to expand upon them to include aspects of logistics that in the 2020s have become increasingly challenging for manufacturing companies is therefore indisputable.

2.2. Factors affecting product design and development from the perspective of logistics

The insights obtained during the analysis can be utilized to build a much simpler model of factors involved in product design and development from a logistics perspective. The first, strictly market- and marketing-related item in the model should be customer expectations. Optimization of the cost of the final product or the finished good drives manufacturing companies to incorporate as much as possible into the product, including not only the solutions expected by the customer but also a number of features that boost the efficiency of the product manufacturing process. This is essentially related to broadly defined expectations of the organization (as a second component in the model), and can be further broken down into smaller groups of factors through deconstruction. Apart from the expectations of the customer and the organization, economic, sociological, and regulatory aspects (E/S/P aspects), arising from the socio-economic typology of the markets for which the product is intended and the legal regime in place – Figure 6. **Customer expectations, corporate expectations, and socio-economic and regulatory aspects are all critical to the process of product design (development) as they ultimately generate a finished good with specific attributes, properties, and architecture.**

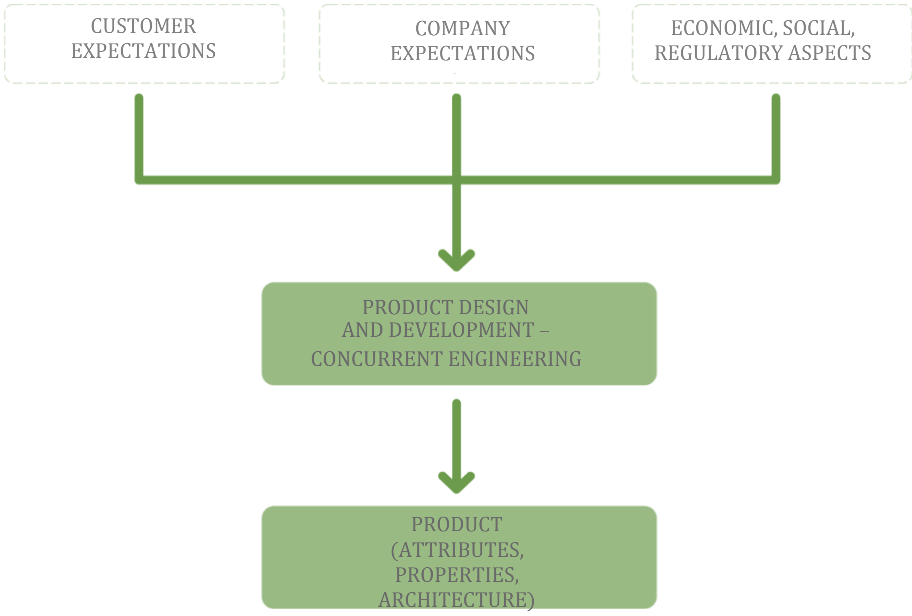

Figure 6. Factors affecting product design
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 62.

Customer requirements are related to their satisfaction with the purchased product. Customer satisfaction has been incorporated into quality management systems and accurately described in ISO 10001[148] as "… customer's perception of the degree to which the customer's expectations have been fulfilled".

It is noted in the latest ISO 9001:2015, in section 5.1.2 (customer focus)[149], that the company should strive to (ensure) that "...customer requirements and applicable legal and regulatory requirements are understood and consistently met". Nevertheless, customer requirements are still not specifically defined, whereas the legal and regulatory aspects raised here justify the need to consider them among the factors contributing to the final design of the product.

Having surveyed the body of literature concerning customer needs, Wang and Tseng[150] classified customer purchase intentions into two main groups: technical requirements and customer subjective preferences that ultimately determine product features.

That, in turn, in the opinion of the authors of the publication, bears upon three areas of design activities that address customer characteristics, functional requirements, and product parameters. From the viewpoint of Design for Logistics, product parameters are the key factor.

In contrast Kujala[151] clearly distinguished between the needs and requirements of the customer (product user). He associated the former, the needs of the user, with problems which make it difficult for users to achieve their goals and/or possibilities of increasing the likelihood of users achieving their goals. An important factor affecting user needs is the context of use. User requirements mean any function and/or quality required to satisfy the user. User requirements are provided and described by the user and they are representative of their point of view. Thus, customer requirements, in line with the quality function deployment method (QFD)[152] are a source of market information about a product to be translated into specific design solutions. Therefore, they assimilate both the anticipated needs of the customer and customer requirements.

[148] PN-ISO 10001, *Zarządzanie jakością, Zadowolenie klienta, Wytyczne dla organizacji dotyczące kodeksów postępowania,* Polski Komitet Normalizacyjny, Warszawa, 2009, p. 15.
[149] PN-ISO 9001, *System zarządzania jakością. Wymagania*, Polski Komitet Normalizacyjny, Warszawa, 2016, p. 12.
[150] Wang Y., Tseng M.M., *Integrating comprehensive customer requirements into product design,* CIRP Annals – Manufacturing Technology 60, 2011, pp. 175-178.
[151] Kujala, S., *User studies: a practical approach to user involvement for gathering user needs and requirements.* Acta Polytechnica Scandinavica, Helsinki University of Technology, 2002, pp. 17-18.
[152] Quality function deployment (QFD) is a commonly used approach to product design and manufacturing which takes customer expectations into account; it was developed in Japan in the late 1960s - Lai-Kow Ch., Ming-Lu W., Quality function deployment: A literature review, European Journal of Operational Research 143, 2002, pp. 463-497 or Kano, N., Seraku, N., Takahashi, F., Tsjui, S., Attractive quality and must-be quality. Hinshitsu, The Journal of the Japanese Society for Quality Control Vol. 14 (2), 1984, pp. 39-48.

Appraisal of the aforesaid customer needs and requirements can be relatively problematic. Back in the late 1990s, a pro-consumer approach to the presented issue would have hardly been contended. Note, however, that the character of market behavior of consumers[153] increasingly often leads to a situation where it is continuously more difficult to find meaningful production engineering solutions to fully satisfy customer needs. A number of factors contribute to this, with growing customization of the final product being one of the leading ones. The authors, therefore, advance a thesis that products that are currently available in the market are a resultant of customer influences, socio-economic environment and regulatory regime, and finally, expectations of the organization. The first two points will not be the object of this book and, although they are very important and relevant in all respects, it should be assumed that the functions corresponding to these elements in the product, if technically possible, have been incorporated into the product. The third item should be deconstructed in terms of the impact of the solutions incorporated in the product, which take into account particular functional needs of the organization including logistic needs.

The authors also point out that the presented classification of customer, organization, and E/S/P expectations also implies that the flexibility of the designer with respect to each of these aspects is different. Adopting the customer focus approach ("the aim of the organization is full customer satisfaction"[154]) and the need to meet legal requirements for the product to enter and remain in the market as a criterion, the designer has the least flexibility when it comes to regulatory compliance because on many occasions, the designer will be compelled to comply with the legal requirements at all costs (e.g. DPF filters in diesel engines). Economic and sociological issues as well as customer expectations offer greater opportunity for a compromise, which means that the designer has some leeway to look for optimal solutions. Expectations of the organization should flexibly assimilate both economic-social-regulatory aspects as well as customer expectations. At the same time, they should allow the organization to generate a profit from its operations. However, it follows from the observations of the market made by the authors that increasingly often insufficient flexibility of manufacturers resulting from dynamic changes in consumer behavior and technological developments is compensated by designing and manufacturing products which, with increasing frequency, require the customer, the market, the economy, etc. to be more flexible, getting the product at a competitive price. This can be achieved with intense marketing efforts employing a range of different methods from

[153] Solomon M.R., *Zachowania i zwyczaje konsumentów. Wyd. VI,* Wydawnictwo Helion, 2006.
[154] One of the main postulates of the TQM philosophy – Hamrol A., Zymonik Z., Zarządzanie jakością, [in:] Knosala R. (ed.), Inżynieria Produkcji. Kompendium *wiedzy* …, op. cit., pp. 565-566.

active marketing tools aided by information technology to neurolinguistic programming. This comes from simple relativism concerning the golden law of the 7Rs of logistics. Consequently, since products that are manufactured are optimized in many dimensions for several variables, they must be inherently imperfect.

When the requirements of the organization are examined in the context of their impact on the various determinants shaping the design, the functional division of the organization should also be regarded. Santarek, Skołud, and Kosieradzka[155] identified marketing, internal control, organization, human resources, finance, administration, research and development, procurement, production, distribution, and sales within the functional structure of the production system. These categories are largely related to the studies, e.g. by Griffin[156], Stoner et al.[157] in which functions in the organization were discussed. From the perspective of this study, it appears that the most important functional areas which have a direct bearing on product design should be in the following spheres of the organization operations:

- marketing and sales (corresponding to customer expectations);
- economic-social-regulatory (corresponding to the E/S/P factors);
- manufacturing - production (corresponding to customer expectations);
- quality (corresponding to customer expectations);
- logistics (corresponding to customer expectations).

Therefore, corporate expectations should be realized on the three main planes: **manufacturing** (associated with the process of manufacturing), **quality** (associated with a broadly understood concept of quality), and **logistics** (associated with flows of goods and their related information throughout the logistic chain). These three core elements play a key role in the emergence of the structure of a product (product attributes, properties, and architecture[158]). Following that assumption, analogy may be drawn between analyzing product parameters and analyzing atoms in a compound (product) and their spatial arrangement - recognizing the overriding importance of E/S/P determinants.

Note also that certain reciprocal action takes place at the point of contact between functional areas of the organization which have a direct impact on the product. On the one hand, specific recommendations are reflected in engineering solutions for the product, while on the other hand, these areas are responsive to the product since they are the recipient of feedback in

[155] Santarek K., Skołud B., Kosieradzka A., *Organizacja i zarządzanie produkcją oraz usługami*, [in:] Knosala R. (ed.), *Inżynieria Produkcji. Kompendium wiedzy …*, op. cit., pp. 30-31.

[156] Griffin R. W., *Podstawy zarządzania organizacjami*, PWN, Warszawa, 2017, p. 377.

[157] Stoner J., Freeman R., Gilbert Jr D., *Kierowanie*, Wydanie II, PWE, Warszawa, 1998, pp. 322-323.

[158] For more on product architecture see [in:] Rutkowski I., *Rozwój nowego produktu. Metody i uwarunkowania …*, op. cit., pp. 21-25.

production processes – Figure 7 (this is illustrated with the two-way arrows connecting the functional areas with the product). These areas are also controlled by the E/S/P and marketing aspects, whether unidirectionally or reciprocally.

Marketing and sales will be interested in some type of "lobbying" for meeting customer expectations in terms of scope, time, cost, and quality[159]. Especially unidirectional impact may often be noticed with respect to regulatory framework as individual legal requirements determine certain solutions. All of these generate product attributes, properties, and architecture.

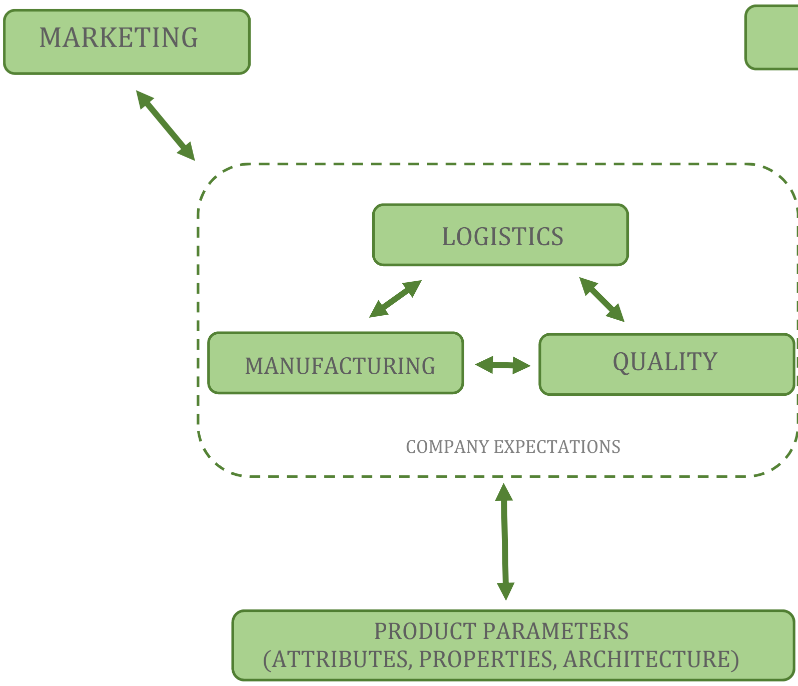

Figure 7. Model of influences on the product – relationships between the influence of functional areas on the product[BGI8]
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 65.

From the standpoint of this study, it is important to note that the conceptual framing of the product in the context of production engineering and the presentation of underlying models and relationships between the determinants shaping the final product made it possible to demonstrate the authors' train of thought leading to the concept of a logistically efficient product. All these considerations clearly prove the need to search for common prerequisites in the area of production engineering which would be advantageous for product logistics. The same should apply to marketing factors. As regards E/S/P requirements, finding shared elements appears to be potentially problematic. The reason for this is that there is a variety not

[159] This can be related to the triangle of constraints – the main parameters of the product – Gierulski W., Wirkus M., *Zarządzanie projektami produkcyjnymi i usługowymi*, [in:] Knosala R. (ed.), *Inżynieria Produkcji. Kompendium wiedzy …*, op. cit., pp. 381-382.

only legal ramifications but also of markets in economic terms and cultural diversity in sociological terms. Therefore, in order to explain the concept of a logistically efficient product, the said analysis appears imperative.

The literature review that has been presented suggests several solutions which could be applied directly to the finished product and which might lead to a tangible effect in the area of logistics and supply chains. The main parameters of the product which have a positive influence on logistics include:

- minimization of the number of parts and sub-assemblies in the final product;
- use of standard parts and sub-assemblies with their standard industrial designations;
- reduction of product dimensions;
- reduction of product weight;
- minimization of packaging use and its impact on the natural environment.

Naturally, the presented example of a set of solutions will be the more effective, the more design-able the finished product is. Nevertheless, the solutions collected herein should certainly contribute to the rationalization of costs associated with logistic processes.

The literature review pointed to selected factors which impinge on product design and development in terms of logistics. Combining them with the elements of DfL that have been singled out as directly related to concurrent engineering (CE), i.e. relationships occurring in the process of design between the designers and the staff in logistics departments, questions of the impact of the implemented solutions on other functional areas in the company as well as the relationships between logistic phases and processes should also affect the final form and shape of the product. That approach provides the groundwork for a logistically efficient product featuring certain manufacturing solutions, which could serve as guidelines for designers designing products with logistics considerations in mind, which will be explained in detail in the next subchapter.

2.3. Logistically efficient product

The concept of DfL and the factors affecting product design and development from the perspective of logistics should certainly be aimed at designing products which are logistically efficient. The concept of a logistically effective product combined with the concept of logistically effective design was signaled by Mather in 1992[160]. Accordingly, the author was

[160] Mather H., *Design for Logistics (DfL) – the next challange for designers …*, op. cit., pp. 7-9.

aware of the importance of anchoring logistic issues within the process of design, although he did not explicitly define the concept.

The notion of a logistically efficient product originates from the research and observation that one of the authors (Bielecki) commenced in 2011 on product prerequisites which facilitate logistic processes. The term "logistically efficient product" was first introduced by Bielecki[161] in 2011. At that time, it was observed that in many cases the effectiveness of measures aimed at rationalization and optimization of logistics is hindered by the product itself due to the fact that products have various parameters (initially defined as features, properties) which make it impossible or difficult to implement the solutions developed for the flow of goods and information about them. A logistically efficient product was defined as a material object of market exchange with a distinct architecture and a set of attributes and properties which allow it to move effectively and efficiently through the procurement, production, distribution, returns and disposal within the organization via logistic processes (transportation, warehousing, packaging, order handling, inventory management) and which enable logistics management to effectively and efficiently integrate order handling, inventory management, packaging, and transportation with third-party stakeholders within the concept of the supply chain[162] outside the organization. Whilst that definition appears to be valid in general terms, it is quite difficult to expound in detail (one of the first definitions presented by Bielecki describes a logistically efficient product as a material object of market exchange that has a set of features and characteristics that enable it to effectively and efficiently move through the procurement, production, and distribution in the organization, whereas outside the organization, allow logistics management to effectively and efficiently integrate transportation, storage, packaging, inventory management, and order handling with third-party stakeholders within the concept of the supply chain[163]).

This can be attributed to the fact that individual design approaches are very rarely exclusively intended for one specific functional area (e.g. logistics) because in most cases they are a resultant of many different arrangements. Furthermore, the definition failed to address Design for Logistics nor did it draw on the available knowledge in the subject area. Note also

[161] Bielecki M., *Conditions of a Logistically efficient product in the context of a Small Manufacturing Enterprises (SME)*, Chapter in a monograph, (ed.) Grzybowska K., Golińska P., *Logistics. Selected logistics problems and solutions*, Publishing House of Poznan University of Technology, Poznań 2011, pp. 281-295, also [in] Bielecki M., *Produkt logistycznie sprawny w małych przedsiębiorstwach produkcyjnych*, Czasopismo Gospodarka Materiałowa i Logistyka, 11/2011 roku, PWE, Warszawa 2011, pp. 2-4.
[162] Bielecki M., *The influence of a logistically efficient product on the logistics of a manufacturing enterprise,* "*Annals of Faculty Engineering Hunedoara – International* Journal of Engineering", Vol. 6, 2013, pp. 175-180.
[163] Bielecki M., *Transport processes of the small manufacturing enterprises (sme) in the context of logistically efficient product*, Research in Logistics & Production 3/2013, Politechnika Poznańska, Poznań, 2013.

that a logistically efficient product should reflect a broader view or a concept of how logistic processes should be carried out.

Analysis of the relevant research output revealed only one study where the concept of a logistically efficient product was considered, and it was only on a conceptual level. Mather[164], who has already been cited, based on the example he analyzed in the article, pointed out that the problem with launching the product on the market was related to the fact that no one had familiarized engineers working on the product with issues in logistics and the need to consider logistic efficiency of the product (in the example, he referred to the use of a large number of non-standard - one-of-a-kind parts). Thus, he explicitly linked logistic efficiency of the product to certain general assumptions of Design for Logistics.

Therefore, following Mather's approach and summing up the literature survey, a logistically efficient product should address the interplay between the following aspects:

- guidelines for Design for Logistics;
- phase and functional approach to logistics;
- product life cycle in a closed-loop system (circular economy);
- advantages of a logistically efficient product for the end user and the organization.

Guidelines for Design for Logistics build the structure of the final product (a final product with specific attributes, properties as well as architecture which, once Mather's publication is taken into account, should enrich that entire system).

The phase approach to logistics, combined with a product life cycle in a closed-loop economy, makes it possible to conclude that the concept of a logistically efficient product should adopt the principles of the circular economy elevating returns and disposal logistics to a "higher rank", and that it should in particular prioritize recycling and reuse of end-of-use products collected from the market. That calls for a model of logistics where logistic efficiency of the product is taken into consideration at each of its stages.

When it comes to the functional approach to logistics (logistic processes), from the standpoint of the Lean philosophy[165], it could be assumed that logistic processes do not generally add value to final products. Transport, storage, packaging, order handling, and inventory management merely compensate for non-perfect products in non-perfect flow systems. Under this assumption, a perfect final product should have such attributes, properties, and architecture that would eliminate or minimize logistic processes resulting from the

[164] Mather H., *Design for Logistics (DfL) – The Next Challenge for Designers …*, op. cit., p. 9.
[165] Womack J., Jones D., *Lean Thinking. Banish Waste and Create Wealth in Your Corporation …*, op. cit., pp. 27-28.

functional classification of logistics in each of the logistics phases (procurement, production, distribution, returns and disposal) at the level of an integrated supply chain.

This, of course, is only logical because for example the packaging process does not in and of itself add any value. Naturally, an optimized approach to this issue (minimizing logistic costs) shows in most cases that it is more advantageous for industrial businesses to pack final products into unit loads (ensuring the stability of shape, dimensions, content, and facilitating count and mechanized handling and storage), which in turn entails the existence of the packaging processes.

With these arguments, the previous definition of a logistically efficient product can be modified to include new considerations. A logistically efficient product should therefore be defined as a physical product (a finished good or a final product), with a distinct architecture, attributes, and properties that take into account the improvement of efficiency and effectiveness of logistic processes in selected phases on the first functional level (processes of transportation, warehousing, packaging, order handling, and inventory management - e.g. increasing transportation effectiveness in the distribution phase) as well as, more broadly - on a strategic level, increase the efficiency and effectiveness of the entire supply chain geared towards the collection and reuse of end-of-use final products in order to satisfy various consumer needs. Paraphrasing this definition, a logistically efficient product could be characterized with the 4Es[166]:

- easy purchase;
- easy production logistic;
- easy distribution;
- easy return of end-of-use products from the market, and reuse of products or their parts.

One example of a logistically efficient product could be a standard nut, e.g. the M12 hexagon nut, made of high quality metal (appropriate hardness, strength, manufacturing precision, etc.). Easy procurement (purchase) would involve buying one type of wire rod that met the requirements (either in bundles or in coils) in a quantity corresponding to the economic order quantity. Easy production logistics would be ensured by narrow specialization of machines, logistic equipment serving the production process that would be tuned precisely and exclusively to the production of the M12 nut. Easy distribution means standard units of sales (e.g. a certain number of packages of 100 M12 hexagonal nuts each per a typical pallet – the EUR/EPAL pallet – as the basic unit of sales). The attributes and properties of the M12 nut

[166] There are at least two reasons for the use of the letter E: the first is that 4Ps could be confused with mix marketing, and the second that the word "easy" best conveys the idea of what is meant.

would enable their recovery from the pool of used final products by reusing them at the site of dismantling or by returning them to the manufacturer, to the distribution department, where they could be put back on the market.

This rather utopian business project (albeit ideal in terms of logistics), carries a whole gamut of risks, restrictions, impossible conditions but nevertheless conveys the idea of the entire model in a deductive reasoning configuration (top-down logic). Of course, it only globally optimizes the first stage of the supply chain by eliminating or standardizing the functional level of logistic processes as it fails to consider the implementation of individual logistic processes in individual phases. However, it does leave the possibility of later optimization of selected optimizable processes from the functional level to improve the effectiveness of logistics.

Having turned to the available literature for possible product designs describing such logistic processes as storage, transportation, and packaging (e.g. Korzeniowski[167], Bogdanowicz[168]), while at the same time relating them to Design for Logistics, it has been possible to identify those product parameters that have an impact on the functional logistics of final (finished) products, including the following:

- attributes:
  - shape;
  - dimensions (width, length, height);
  - mass;
  - state of matter;
  - smell;
- properties:
  - stackability;
  - hygroscopicity;
  - shrinkability;
  - self-weldability;
  - hardness;
  - corrodibility[169] etc.;
- product architecture:
  - standardization;

[167] Korzeniowski A. (ed.), *Magazynowanie towarów niebezpiecznych, przemysłowych i spożywczych …*, op. cit., pp. 20-39.
[168] Bogdanowicz S., *Podatność. Teorie i zastosowanie w transporcie …*, op. cit., p. 38.
[169] Łatka U., *Technologia i towaroznawstwo …*, op. cit., pp. 109-112.

- multifunctionality;
- modularity;
- limited personalization (customization) of the product, etc.

That said, the classification is rather detailed, which means that generally with products galore on the market, it would not be practical to determine all the attributes and properties that could either positively or negatively affect the flow of goods and information in individual processes. Nevertheless, the fact that the classification provided relates directly to the product itself is clearly evident.

By comparing the classification presented earlier against the selected components of the DfL concept, it is possible to isolate solutions implemented in the product (DfL guidelines) that could contribute to greater efficiency and effectiveness of logistics and supply chains. This, however, entails establishing a common denominator for the classification of the entire DfL content that has previously been discussed. To that end, it is proposed to categorize the solutions into three main groups: the level of the product (which will include the aforesaid parameters), the level of the process, and the level of the supply chain.

The first group of solutions should be comprised of elements (DfL guidelines) related to the product itself (**the level of the product**), i.e.:

- standardization of raw materials, materials, components, and other elements of which the final product is made;
- multifunctionality of raw materials, materials, components and parts included in the final product, and of the final product itself;
- minimization of the number of parts in the finished product;
- optimization of product characteristics (dimensions, shape, weight, etc.) for logistics;
- optimization of product properties (strength, fragility, stacking capacity);
- streamlining product architecture and structure;
- limiting the set of end item configurations (minimizing product assortment groups);
- pushing the decoupling point as far in the order handling process as possible - deferring product personalization;
- application of modularity principles;
- incorporation of multiple design aspects concurrently at the earliest possible stages in the design process;
- limiting the set of end item configurations (limiting personalization).

Standardization and multifunctionality are the two most important issues here. Standardization of elements and assortments is tied to the use of available, generally standardized solutions. It may take different forms and approaches depending on the criterion of the classification. Considering traceability of standardized parts, standardization could be classified into direct, indirect, and non-traceable. The first one, direct standardization, takes advantage of the solutions available on the market on one-to-one basis. That means that the standardized items are not modified in any way, are unequivocally traceable, and available from the market. Indirect standardization occurs when a certain final product is sold under a different name but, due to its characteristics, qualities, and information details, it is directly traceable. Non-traceable standardization is meant to use standard elements but with virtually no possibility of tracing them other than by means of specialized knowledge and/or equipment. Non-traceable standardization is also manifested in the application of modularity. Modularity understood as the use of base modules of the product designed specifically to allow for configuring, dismantling, and reconfiguring the product back to the base units that the modules represent. Modules are therefore a relatively more complex standard elements which allow the system as a whole to achieve economies of scale.

Multifunctionality of components may come down to the use of a certain structural design to perform a variety of functions. One good example would be the use of a screw sometimes as a fixing element, while at another time as a standard fastener. As a result, the benefits of standardization could be further increased.

The second group of solutions concerns **logistic processes** (functional classification of logistics). Among the available approaches, the following types of design can be distinguished:

- for transportability:
    - minimizing transportation-specific requirements;
    - optimizing transportation units;
    - using standard infrastructure;
- for warehousing:
    - minimizing storage-specific requirements;
    - using standard infrastructure;
- for packaging:
    - minimizing packaging use;
    - minimizing packaging environmental impact.

These three subgroups will be associated with **the physical flow of the product**. Whereas among the subgroups responsible for **the organization of that flow** there will be design:

- for order handling:
  - taking quality aspects into account in the process of order handling – errors in order processing, etc.;
  - creating customer friendly order handling;
- for inventory management:
  - including in the design process issues related to demand forecasting and supply planning in each phase separately;
  - considering in the product design process issues related to minimizing inventory levels in each phase separately.

The third group of measures, related to **the supply chain**, will be the most elaborate. It will focus on considering opportunities for supply chain selection, possible reconfigurations of the existing supply chain, using design for demand and supply planning to achieve economies of scale, reducing warranty and service costs, after-sales services, the dynamics of changes in the localization of the supply chain stakeholders, mergers, acquisitions, and other strategic aspects related to the supply chain and its management. Needless to say, beyond the points listed above, it should also be ensured that the principles of process concurrency and parallelism as well as considerations related to the localization of the supply chain actors are taken into account in product design, although these elements could actually be included in the area of the supply chain.

Product personalization (customization), which enables moving the decoupling point as close to the customer as possible, emerges as another quite significant issue. Combining the advantages of mass production with the ability to offer a personalized product. Mass customization[170] brings together conflicting concepts, and therefore its implementation requires a compromise between the expectations of the manufacturer and the customer. Customers are drawn into the process of product development their influence, however, may resonate across different phases of the production process. Four degrees of customization with decreasing level of product personalization are identified in the literature:

- pure customization;
- tailored;
- standardized;
- pure standardization.

[170] Bielecki M.,Hanczak M., Mass customization as one of the key elements of logistic efficiency of a product, Acta technica corviniensis – Bulletin of Engineering, Fascicule 3 / /2016 [July-September]. Retrieved October 10, 2017, from http://acta.fih.upt.ro/ACTA-2016-3.html, pp. 27-30.

In pure customization, the customer participates in the design of the product, which makes it possible to create a product that meets their individual preferences. Tailored customization assumes that the customer is involved at the manufacturing phase. That means that the shape and dimensions of standard components can be modified in accordance with customer requirements. The involvement of the customer only at the assembly or distribution phase, which happens in standardized customization, limits product customization to the extent allowed by the specification of standard options. In pure standardization, the needs of the individual customer are not considered at all. Given this definition of customer involvement in the process of product development, it is important to note that in many cases, the wishes of the customer do not necessarily coincide with the requirements of effective and efficient corporate flows. Furthermore, a number of situations could be identified where these needs could be at odds with the organization logistics objectives. For this reason, it has been an increasingly common business practice to try to build a business model where logistic efficiency of the product comes forth as a key factor of competition. In principle, the concept of design for excellence (and, most of all, of Design for Logistics and supply chain) anticipates "assimilation" in the product of the greatest possible number of attributes and properties that should contribute to improved effectiveness and efficiency of the flow of goods and information about them.

No less important appears to be the group of considerations related to the realm of **logistic infrastructure**. The following among them:

- using standard infrastructure solutions to handle products in a variety of processes (e.g. standard European pallets, standard fork spacing, etc.);
- including development trends in logistic infrastructure (e.g. Virtual Reality);
- using standard automatic identification systems and related solutions (RFID – *Radio Frequency Identification*, NFC – *Near Field Communication*).

Logistic standardization emphasizes blending aspects associated with logistics processes in the supply chain (transportation, storage, packaging, order handling, and inventory management) into the process of design. Minding the fact that specific products are packed in secondary packaging and thereafter arranged into unit loads which enable continuous tracking of flows throughout the logistic chain is another challenge for a logistically efficient product. The difficulty in finding, in many cases, solutions to effectively support all aspects of the process is indicative of the necessity to optimize only selected parameters of the product – the ones that have the greatest relevance to the logistic operations of the organization.

The determinants of Design for Logistics and supply chain discussed above will come forth as the cornerstone of the description of a logistically efficient product and its relationship to Design for Logistics.

Clearly, the classification of product attributes and properties from the viewpoint of the construction of the final product should first be confined to a single unit of the final product reaching the market, and, on another level, to standard unit loads subject to logistic processes tasked with delivering a single final product to the market. The rationale for this assumption is, of course, the customer, as the final validator of the product attractiveness, and the consequences ensuing from that for the company – possible profits or losses. Thus, the design of the final product may be reduced to what is known as product parameters:

- product attributes (basic shape and materials used to make it; dimensions, mass, all of which can be optimized for logistics);
- physical properties of the product that affect logistic processes, which, like the attributes, may be subject to logistic optimization (vulnerability to transportation/warehouse operations, ease of handling, the necessity to use and design packaging);
- product architecture (linked to standardization/modularity, multifunctionality of components and parts as well as product configurability – customization).

The next assumption follows from a vast range of products distinguished by such characteristics as e.g. density, state of matter, smell, etc., and/or chemical and biological properties. Consequently, products should be narrowed down to a group for which these attributes and properties will have a neutral impact on logistic processes. This, in a natural way, eliminates from consideration final products which are output vectors of continuous processes[171] to which aspects such as modularity, standardization, etc. are simply not applicable.

At this point, an attempt should also be made to systematize the following four basic relations:

- guidelines of Design for Logistics (DfL) to product parameters (attributes, properties and architecture);
- product parameters to logistic phases;
- design guidelines to logistic phases;
- product parameters to logistic functions (processes).

[171] „…continuous processes, typically equipment-based, permanently coupled to production plants, usually automated production automated with "rigid" systems …" – Durlik I., *Inżynieria Zarządzania ...,* op. cit., pp. 61-62.

The first of the above listed points comes down to the assignment of the DfL guidelines analyzed in the previous chapters to elements of product design - Table 3. Table 3 shows unambiguously that the DfL guidelines mainly affect the architecture of the product. Optimization of attributes and properties, which is manifestly related to them, essentially remains within the realm of the designer's conceptual idea. Standardization/modularity, and thus minimization of the number of parts, multifunctionality, and reduced configurability are the domain of product architecture.

Table 3. Relationships between product parameters and their elements

Parameters / **Elements**	**Attributes**	**Properties**	**Product architecture**
Basic shape	strong	weak	weak
Basic dimensions	strong	weak	weak
Basic weight	strong	weak	weak
Vulnerability to transportation/warehousing	weak	strong	weak
Addressing handling aspects	weak	strong	weak
Requirement to use/design packaging adapted for the product	weak	strong	weak
Standardization/Modularity	weak	weak	strong
Multifunctionality	weak	weak	strong
Limited product configurability/Pushing the decoupling point	weak	weak	strong

– strong relationship
– weak relationship

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 76.

On that basis, it would be appropriate to try to relate the proposed product parameters to logistics processes. The assumption can be formulated that product architecture (as assigned to the guidelines) will be only indirectly relevant for transportation, warehousing, and packaging processes, however, it will be of critical importance for inventory management and order handling where the context of information and decision making is much more important than the context of the flow of goods – Table 4.

The reason why that happens is that the basic objective of the packaging process as well as of the actual packaging is to perform the primary functions of packaging (to protect, store, facilitate transportation, handling, to inform, to be disposed of[172]).

Table 4. Model of the influence of the parameters of the final product on processes defined in the functional classification of logistics

	Warehousing	**Transportation**	**Packaging**	**Order handling**	**Inventory management**
Product attributes	strong	strong	average	weak	weak
Product properties	strong	strong	average	weak	weak
Product architecture	average	average	average	strong	strong

(dark green bar) – strong support of the guideline for the logistic phase
(light green bar) – average support of the guideline for the logistic phase
(grey bar) – weak support of the guideline for the logistic phase

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 76.

Standard mass-produced products greatly simplify both order handling and inventory management. Whereas attributes and properties that generate the physical shape of the product will affect transportation and storage processes as well as, indirectly, processes of packaging and the packaging itself. The reason why that happens is that the primary objective of the packaging process as well as of the actual packaging is to perform the primary functions of packaging (to protect, store, facilitate transportation, handling, to inform, to be disposed of [173]).

Referring once again to the utopian vision of a logistically efficient product – the M12 hexagonal nut, it is possible to demonstrate relations between product parameters and the phase approach to logistics – Table 5. Note however that the range of impact of product attributes and properties on logistic phases will be different from that exerted by product architecture.

Since product attributes and properties determine the physical form of the product, they will play a central role in the logistic phase of distribution and the logistic phase of returns and disposal, and to some extent in the phase of production logistics. Generally, in the final phase

[172] Mokrzyszczak H., *Logistyka. Podstawy procesów logistycznych …*, op. cit., p. 157.
[173] Ibid.

of production logistics, individual final products are combined into unit loads (or individual final products are packaged) to go into the distribution phase.

Table 5. A model of relations between product parameters and logistic phases

	Procurement phase	Production phase	Distribution phase	Returns and disposal phase
Product attributes	[weak]	[average]	[strong]	[strong]
Product properties	[weak]	[average]	[strong]	[strong]
Product architecture	[strong]	[average]	[average]	[strong]

[strong] – strong support of the product parameter for the logistic phase
[average] – average support of the product parameter for the logistic phase
[weak] – weak support of product parameter for the logistic phase

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 77.

The phase of distribution mainly involves transportation and storage processes associated with the flow of goods as well as order handling and inventory management processes more closely related to the flow of information about goods. Product attributes and properties also play a role in the logistic processes of returns and disposal. Collection of end-of-use products or their eventual disposal essentially relies on transportation processes, which is why attributes and properties will play a fundamental role here. The architecture of the product is important only in terms of returns logistics. It inevitably affects the possibilities of taking back used parts (closing the loop in product cycle – the circular economy[174]) and the prospect of their further use, e.g. recovery of standard elements (screws) whose level of wear still allows them to be reused in finished goods or final products. To illustrate this issue, a viable model of relations between the DfL guidelines and logistic phases is provided – Table 6.

The next model of relations shows the anticipated impact of the DfL guidelines with regard to the phase approach to logistics. Among the guidelines that have been analyzed, standardization, modularization, and minimization of the number of parts in the final product as well as the reduction of product configurations have the greatest potential impact on each of

[174] The vision of a closed-loop economy is outlined, e.g. in the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Towards a circular economy: A zero waste program for Europe. Retrieved March 16, 2020, from https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=celex%3A52014DC0398

the logistic phases. At the same time, that is also the element which is the hardest to examine and which requires organizing the data and information on the subject matter, i.e. knowledge, as well as the aid of information technology in the analytical process[175].

Table 6. Model of relations between the DfL guidelines and logistic phases

	Procurement phase	**Production phase**	**Distribution phase**	**Returns and disposal phase**
Optimization of attributes	weak	average	strong	average
Optimization of properties	weak	strong	strong	average
Optimization of product architecture	strong	strong	weak	strong

(strong) – strong support of the guideline for the logistic phase
(average) – average support of the guideline for the logistic phase
(weak) – weak support of the guideline for the logistic phase

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 78.

Standardization, in the area of procurement, where the purchase of standard raw materials, materials, semi-finished products, etc. in the market entails benefits such as greater availability of procurement products on the market, lower risks associated with the necessity to change suppliers, better price due to availability, streamlined order placement procedure, etc., should clearly be optimized to maximize the use of standard solutions available on the market.

Similarly, in the area of production logistics, standardization enables maximization of the effect of mass production simplifying a number of the processes of the flow of goods – within the plant. The effect of standardization will be less significant for distribution, nevertheless its relevance rises with respect to returns and disposal logistics, where, according to the principles of the circular economy, standardization of parts provides greater opportunities either to reuse standard parts recovered from end-of-use final products or to increase the effectiveness of disposal processes in terms of achieving economies of scale (the greater the number of product parts regularly recovered from the market, the stronger the rationale for introducing appropriate disposal arrangements).

[175] The problem of information systems supporting knowledge management has been expounded by Duda – Duda J., *Systemy informatyczne wspomagające zarządzanie wiedzą*, [in:] Knosala R. (ed.), *Innowacje w zarządzaniu i inżynierii produkcji. T. 2*, Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole, 2015, pp. 60-74.

Similar rationale holds for modularity, as a derivative of standardization, although at this point, the relevance of modularity for returns and disposal logistics will be considerably lower. It will play a more important role in the distribution process. Minimizing the number of product components (which is related to product architecture) significantly facilitates logistic processes of procurement (fewer parts to be ordered), production, and returns and disposal logistics. Its effect on distribution is somewhat weaker as it does not matter whether e.g. a chair consists of 5 or 10 elements, since the product and its packaging will be identical for both scenarios.

The last item that deserves to be recognized is the reduction of product configurability, which is strictly related to the repositioning of the decoupling point.

Generally, beyond returns logistics, limiting product configurability will boost mass production with positive effects on procurement, production, and distribution logistics.

Certainly, the packaging alone also has a direct impact on competitiveness, increasing the value of the product. The main features of packaging that affect the value of the product include: visual appeal, functionality, convenience, ergonomic design, safety, comprehensibility, cost, eco-friendly design, and prestige[176]. A distinctly competitive role for packaging becomes apparent, which, in terms of logistic efficiency of the product, will be of secondary importance on account not of willful negligence but rather of the need to keep the model to the necessary minimum.

The remaining logistic processes are polarized in line with the logic of the predominance of the flow of goods in some processes (transport, storage, packaging) and of the flow of information (inventory management, order handling) in others – Figure 8.

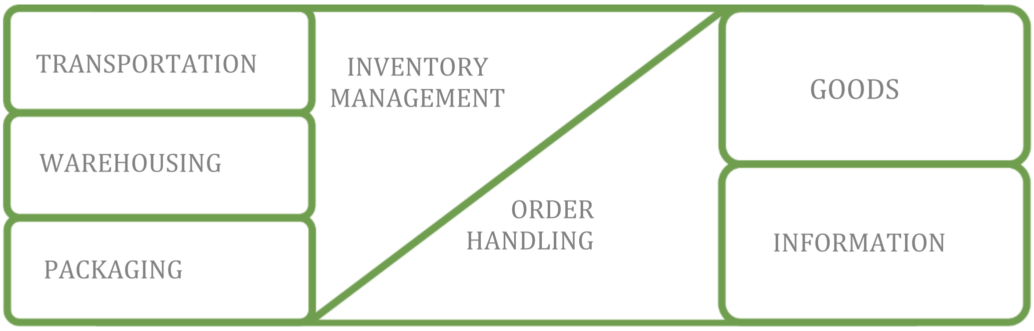

Figure 8. The extent of product impact on logistic processes in terms of goods vs. information
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 79.

[176] Kucińska – Landwójtowicz A., Jurczyk-Bunkowska M., *Znaczenie innowacji w opakowaniach jednostkowych w podnoszeniu konkurencyjności wyrobów*, [in:] Knosala R. (ed.), *Innowacje w zarządzaniu i inżynierii produkcji T. 1.*, Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole, 2015, pp. 88-89.

Since Bendkowski[177] claims that optimal logistic practices require that the three fundamental rules of logistics be adhered to, i.e.: the entire system and its components must be aligned with the size and frequency of the movement of materials, the degree of the system integration should be maximally high, and the system should have a minimum number of bottlenecks and be capable of flexibility, therefore it appears uncontroversial to think that the product in and of itself should have a bearing on these postulates. Assuming that this is the case, the next step would be to identify relations between the previously defined DfL guidelines for optimization of product attributes, properties, and architecture, and individual logistic processes.

The next model shows the influence of the DfL guidelines on logistic processes as defined in the functional classification of logistics – Table 7.

Table 7. Model of the influence of DfL guidelines on the functional classification of logistics

	Warehousing	**Transportation**	**Packaging**	**Order handling**	**Inventory management**
Optimization of attributes	[strong]	[strong]	[strong]	[weak]	[weak]
Optimization of properties	[strong]	[strong]	[strong]	[weak]	[weak]
Optimization of product architecture	[average]	[average]	[average]	[average]	[average]

[strong] – strong support of the guideline for the logistic phase
[average] – average support of the guideline for the logistic phase
[weak] – weak support of the guideline for the logistic phase

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 80.

This model is intended to assign the DfL guidelines to specific elements of the product structure. What follows from this model is that optimization of attributes and properties will promote processes related to the flow of goods, i.e. transportation, packaging, and warehousing. On the other hand, architecture-related items of the product structure will be involved in the sphere closer to the flow of information about the product. Standardization and its related modularization continue to have an indirect relevance for the analyzed questions, although throughout all of the processes.

[177] Bendkowski J., *Logistyka produkcji procesowo zorientowanych heterogenicznych systemów produkcyjnych. W kierunku nowego paradygmatu*, Zeszyty Naukowe Politechniki Śląskiej, Organizacja i Zarządzanie nr 70/2014, Gliwice, 2014, p. 48.

The model distinctly implies that optimization of attributes and properties will promote processes related to the flow of goods, i.e. transportation, packaging, and warehousing. On the other hand, architecture-related elements of the product structure will be involved in the sphere closer to the flow of information about the product. Pushing the decoupling point towards the market should be considered an important challenge that could greatly improve the efficiency and effectiveness of both processes: inventory management and order handling. However, the extent to which attributes and properties have an impact is considerably limited in this case. This is basically due to the objectives set for order handling and inventory management. In essence, product attributes and properties do not in any way affect order handling and inventory management processes. Only product architecture (in terms of personalization, range of products and assortments) may have a bearing on this phenomenon.

The above models suggest that a product can be viewed as being logistically efficient solely from the standpoint of the organization. Nonetheless, it needs to be pointed out that logistic efficiency of the product should also be considered from the perspective of the final customer – the end user of the product. For this type of customer, logistic considerations may be one of the factors determining purchase, although the degree of their influence on the decision whether to buy the product is likely to be considerably less substantial.

Adopting Pogorzelski's[178] dichotomous categorization of motivation in consumer purchasing behavior into utilitarian (related to the functional characteristics of the purchased products) and hedonistic (with non-material characteristics playing the main role), it is possible to conclude that the topic of a logistically efficient product can be embedded in both groups, which does not necessarily imply, however, that it takes precedence over other determinants. For it would be difficult to imagine that within utilitarian motivation, factors facilitating logistics would be more important than the functions inherent in the product. Of course, for high-volume, bulky products, logistic issues will also play a major role, nonetheless, the functionality of the product appears to be unquestionably more relevant. The same applies to hedonistic motivation in consumer purchasing behavior where logistic efficiency will not be salient.

Taking a closer look at the entire marketing concept of the product, one should note that if the customer is following a rational (utilitarian) approach to the purchasing process, he/she ought to opt for products that promise the greatest usefulness[179]. The context of a logistically efficient product will therefore be narrowed down to integrating logistic aspects into the product

[178] Pogorzelski J., *Pozycjonowanie produktu*, Polskie Wydawnictwo Ekonomiczne, Warszawa, 2008, p. 62.
[179] Smalec A., *Nabywca w procesie podejmowania decyzji zakupu*, [in:] Rosa G., Perenc J. (eds.), *Zachowania nabywców*, Wydawnictwo Naukowe Uniwersytetu Szczecińskiego, Szczecin, 2011, p. 158.

in a way that ensures that for the end-user they facilitate the logistic processes on the part of the end customer. Consumer logistics processes could be based on the functional classification of logistics (in order to retain the common denominator of the analyzed phenomenon), although, for obvious reasons of expediency or validity of specific logistics processes, it requires revision – Table 8.

Table 8. Plurality of objectives and rationales for logistic processes as regards the final consumer and the production company

Functional classification of logistics	Context of the production company	Consumer context of logistic processes
Packaging	Packaging and packaging process optimized for cost and logistics	Packaging facilitating transport, storage, easy disposal, no packaging process
Transportation	Standard unit loads	Non-standard single items or multi-packs, easy transport to the household
Warehousing	Standard unit loads suitable for a variety of warehousing infrastructure	Non-standard single items or multi-packs for easy storage in the household
Order handling	Depending on the business model, mainly geared towards wholesale customers, reduction of product assortment, and standardization	involving mainly the purchasing process, the simpler the better, personalization, the 7Rs rule
Inventory management	Stability of demand, quality, and delivery guaranteeing recurrent procurement cycles – fixed size ordering and reorder point strategies – Wilson formula[180]	Generally, not applicable

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 82.

Looking through the prism of the production company, the process of packaging as well as the packaging design are tasked with ensuring a smooth flow of the product through the distribution area (only logistic context is considered).

For the first of the featured logistic processes, there are fundamental differences between the context of the production company and the consumer with regard to logistic efficiency. From the standpoint of the manufacturer, the packaging process as well as the packaging design

[180] Sarjusz-Wolski Z., *Sterowanie zapasami w przedsiębiorstwie …*, op. cit., p. 25.

are tasked with ensuring a smooth flow of the product through the distribution area (only logistic context is considered).

Mokrzyszczak[181] called attention to the six cardinal functions that packaging should fulfill from the viewpoint of logistics, among them:

- protection (packaging is intended to protect the goods contained therein during transportation and warehousing processes);
- storage (enabling optimization of the warehousing process);
- transportation (enabling optimization of the transportation processes);
- handling (enabling optimization of loading processes);
- information (facilitating identification of key information about the goods throughout the logistic chain);
- disposal (environmental impact of packaging).

Note that the classification provided only applies to the perspective of the company that, within the framework of its distribution and returns logistics, must ensure effective and efficient flow of products through the entire logistics channel. However, neither procurement and production logistics nor the final customer are considered within this approach.

From the viewpoint of the end consumer, it is increasingly evident that packaging poses a serious problem. Indeed, rarely does the packaging of a product make logistic processes easier for businesses and consumers alike, which is even more evident in the context of waste packaging that final customers are left with after the purchase (an important aspect of returns and disposal logistics).

The analysis of transportation and storage processes from the vantage point of organizations lends support to the thesis that essentially all their efforts seek to standardize unit loads to those most prevalent in logistics. Euro pallets, standard containers, semitrailers, warehouse racks, and other solutions of this type render the issues of transportation and storage increasingly demanding for designers. If the same processes are applied to the final customer, it becomes apparent that, in that case, implementation of solutions facilitating transportation and storage tends to be geared towards multiplying sales, e.g. (multi-packs), rather than aiding transportation and storage of products bought by the customer. Consequently, the issue of logistics from the standpoint of the final customer is out of symmetry with the solutions developed by industry.

[181] Mokrzyszczak H., *Logistyka. Podstawy procesów logistycznych…*, op. cit., p. 157.

With production companies, the area of order handling leans towards standardization and repeatability of orders. In principle, an ideal solution would involve offering a single product on the market, with absolutely no possibility of personalization, sold in standardized unit loads in identical quantities (which would definitely affect inventory management). Not only would that approach guarantee stability of order handling processes, but it would also have the potential to improve quality-related aspects. From the point of view of the final consumer, order handling is understood as the process of buying a product. Expedient completion of the process of purchase (customer service) comes forth as a priority of the said operations. Since the subject matter under discussion concerns the purchase process, it is extremely difficult to imagine not having the possibility of choice, e.g. of the color of the product, something that is very obviously taken for granted by the end customer.

The last process, inventory management, is very important from the point of view of the production company. Keeping inventory to an appropriate level of customer service (the level of customer service is equivalent to the probability of satisfying demand in any given period of order fulfillment[182]) entails either flexibility and agility of production processes or holding stock. The flexibility and agility of production processes are certainly influenced by the design of the product. Therefore, design for manufacturing (DfM) and design for assembly (DfA) are two methods whose application makes perfect sense. Unless flexibility and agility are strategic assets of the organization, there is the issue of inventory management, which, again, is considerably affected by product architecture. Note that product architecture knits together the sphere of inventory management. For the customer, inventory management is basically irrelevant. Indeed, it could hardly be imagined that consumer choices did to a large extent take into account the sphere of inventory management of products purchased by the household. Therefore, it is reasonable to assume that, from the consumer perspective on inventory management, this aspect of a logistically efficient product is not going to be vitally important.

The underlying assumption of the concept of a logistically efficient product is that product parameters (attributes, properties, architecture) have a meaningful influence on logistics management in the enterprise[183]. However, it now appears that the revised definition of a logistically efficient product provided at the beginning of the chapter, failed to include at least three major aspects:

[182] Sarjusz-Wolski Z., *Sterowanie zapasami w przedsiębiorstwie …,* op. cit., pp. 44-45.
[183] Bielecki M., Szymonik A., *The impact of logistics Security conditions on the logistical efficiency of the product*, Acta Technica Corviniensis – Bulletin of Engineering – Online supplement of the Annals of Faculty Engineering Hunedoara – International Journal of Engineering, Fascicule 1, 2015.

- the first concerns the question of information about the object of the flow (goods), which is an inherent part of logistic processes;
- the second concerns the customer as the recipient and beneficiary of logistic efficiency of products;
- the third concerns the context in which a logistically efficient product will be discussed.

The problem of information about the products that are the objects of the flow is largely associated with information systems which in logistics are computer-aided. To develop a vision of product design guidelines that would take into account modern technologies of goods identification, e.g. Radio Frequency Identification (RFID) and Near Field Communication (NFC) would be a formidable task. After all, information technology revolution and miniaturization made it possible to build transmitters so small that there is virtually no need to specifically consider their parameters in product constructs.

As regards the second aspect, Bielecki[184], in further conceptual modifications, referred to the customer aspect, describing a logistically efficient product as a commodity with a set of features facilitating or supporting logistics management, thus allowing both the manufacturer and the customer to achieve certain benefits. As was already pointed out the achievement of mutual benefits by the customer and the company could often be hindered or could even lead to a peculiar conflict of interest.

The third aspect, of systematizing the concept of a logistically efficient product, also requires that a plane be defined on which the discussed problem will be dealt with. Again, the point is to find a shared ground between the company and the customer. This is important inasmuch as a logistically efficient product may be construed differently by the company whose aim is to maximize certain economic, technological, etc., parameters. The final customer purchasing the final product on the market may approach logistic parameters of the product in quite another way.

Packaging provides a good example. From the point of view of the production company, packaging tends to serve warehousing, handling, transportation, protection, and identification purposes. Whereas the customer perceives it as reinforcing the concept of the product, ensuring its safety, increasing convenience, minimizing logistic cost, promoting marketing communication, etc.[185].

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[184] Bielecki M., *The influence of a logistically efficient product on the logistics of a manufacturing enterprise …, op. cit.*, pp. 175-180.

[185] Kucińska – Landwójtowicz A., Jurczyk-Bunkowska M., Z*naczenie innowacji w opakowaniach jednostkowych w podnoszeniu konkurencyjności wyrobów*, [in:] Knosala R. (ed.), *Innowacje w zarządzaniu i inżynierii produkcji …*, op. cit., 2015, p. 91.

Thus, to recapitulate the thoughts and ideas presented so far, a logistically efficient product should be considered on several planes:

- application of DfL guidelines in the product as such;
- product parameters – physical structure of the final product (attributes, properties, architecture of the product);
- influence of the physical structure of the final product and the DfL guidelines on the phase and functional contexts of logistics;
- benefits of logistic efficiency of the product for the final customer and for the enterprise.

Having considered the arguments advanced above, the final definition of a logistically efficient product can now be given. **A logistically efficient product will be defined as a final product (or a finished good) having certain architecture, attributes, and properties which partially or fully accommodate logistic and supply chain aspects, improving the efficiency and effectiveness of logistic processes in selected phases on the first functional level (transportation, warehousing, packaging, order handling, and inventory management processes – e.g. increasing transportation effectiveness in the distribution phase), and also on a broader, strategic level, raising the effectiveness and efficiency of the overall supply chain with a focus on collection and reuse of end-of-use final products in order to satisfy various consumer needs. Therefore, it comes down to the accomplishment of the objectives of the 5Es:**

- **Easy Purchase;**
- **Easy Production Logistics;**
- **Easy Distribution;**
- **Easy Return of end-of-use products from the market and reuse of products or their parts;**
- **Easy Customer Logistics.**

A logistically efficient product should provide a competitive advantage which can be characterized in terms of flexibility, quality, and reliability[186]. It follows from the proposed definition that the efficiency and effectiveness of the flow are certainly responsible for productivity, however, flexibility has to be associated with the decoupling point. Meanwhile, quality remains a separate issue which will not be examined to any large extent at this stage in the research. Furthermore, at least two other factors need to be expounded before the conceptual framework for the proposed approach is complete.

[186] Lis S., Santarek K., Strzelczak S., *Organizacja elastycznych systemów produkcyjnych*, PWN, Warszawa, 1994, pp. 16-17.

The first one is connected with the assumption that not all products offer the same possibilities to modify their attributes, properties, and architecture to the same degree. Which means that for natural reasons (purpose, structure, functionality, regulatory requirements) there will be limitations to the possibility of designing changes to support logistics. Therefore, an attempt should be made to develop a model to describe the phenomenon of product amenability.

The second element that needs to be elucidated, which is directly related to the logistically efficient product, is the idea of logistic efficiency of the product. Since a logistically efficient product will be considered in terms of 'logisticality' of the physical final product, logistic efficiency of the product should come forth as a concept integrating the approach to the design of attributes, properties, and architecture of the final product in terms of their impact on the efficiency and effectiveness of logistics, the physical product in the supply chain, and also taking the final customer into consideration.

2.4. The concept of logistic efficiency of the product

Formulation of the concept of logistic efficiency of the product should serve three basic objectives and should be based on simple assumptions. In designing a product, the following three fundamental principles should be applied: simplification, homogenization, and interchangeability[187]. Accordingly, a model of logistic efficiency of the product ought to take into account these postulates but it also needs to be refined with the three further aims:

- creating a well-structured model of logistic efficiency of the product, thereby making it possible to effectively identify the parameters of the product responsible for its logistic efficiency as well as the determinants of logistic efficiency of the product;
- creating a model of logistics which has regard to the circular economy on which logistic efficiency of the product could rest;
- including methods and methodology to show different ways of approaching logistic efficiency of the product.

The term "efficiency" is defined differently depending on the context. Two of the definitions provided in the PWN Online Encyclopedia have been selected[188] that are relevant to the subject matter under discussion:

- as a technical term, the proportion of the outcome achieved to the resources used expressed as a percentage;
- in mechanics, the proportion of the work done to the energy supplied.

[187] Wróblewski K., *Podstawy sterowania przepływem produkcji,* Wydawnictwo Naukowo-Techniczne, Warszawa, 1993, p. 14.
[188] https://encyklopedia.pwn.pl/szukaj/sprawność.html

From the vantage point of logistics, application of the concept of efficiency so defined would be highly problematic. The difficulty lies in measuring the logistic effect of an operation while at the same time calculating the resources spent. Since logistic processes do not bring any specific value to the product, measuring efficiency defined in either way could prove to be challenging.

Measurement of the logistic effect of operations could be based on the previously cited Shapiro and Heskett's[189] logistic rule of 7Rs. However, it should be noted that insofar as the delivery of the right product (such as was ordered by the customer without going into its attributes, properties, architecture, and functions beyond the scope of logistics), in the right quantity, to the right customer, to the right place, in the right condition are possible to assess (these processes take place on a daily basis in the sphere of procurement, production, and distribution), it is somewhat more difficult to evaluate the right quality (its relation to the right condition) and, above all, the right cost which in logistics will be always directed towards the minimum and, from the customer's point of view, will be relativized to their affluence. Appropriate tools to analyze and measure logistic efficiency of products should therefore be proposed. These can be based both on metrics (numbers and figures that describe analyzed phenomena and allow comparing them to other phenomena by providing their measure[190]), as well as indicators (understood as relative numbers expressing relations between certain quantities[191]).

As regards logistics measures, Nowicka-Skowron's[192] publication should be considered first. The author takes a two-way approach to the measurement of the efficiency of logistic systems: global and by individual subsystems. She argues that as far as global efficiency of the logistic system is concerned, its calculation is based in essence on comparing the effects attained by the system with the outlays expended on its operation[193]. Since it is rather difficult to define an effect of a logistic system operation, the author decided that it should be understood as effecting the flow of goods, of comparable quality, but aiming for the minimum cost. Concerning indicators of the performance of logistic subsystems, Nowicka-Skowron arranged them into four basic categories: structural and systemic, productivity, economy, and quality, by assigning specific indicators to each of the three phases (except for the phase of reverse logistics), e.g. the average shipping time is a qualitative indicator in the distribution phase.

[189] Shapiro R., Heskett J., *Logistics Strategy-Cases and Concepts …*, op. cit., p. 6.
[190] Twaróg J., *Mierniki i wskaźniki logistyczne …*, op. cit., p. 23.
[191] Ibid., p. 24.
[192] Nowicka-Skowron M., *Efektywność systemów logistycznych …*, op. cit., pp. 68-71.
[193] Ibid., p. 117.

Similarly defined are indicators with regard to functions, e.g. transportation cost per order is a measure of the economy of the flow of materials and transportation.

Twaróg[194], from the perspective of the logistics management approach, classifies logistic metrics into inward bound and outward bound. The inward bound metrics include:

- level of customer service;
- efficiency of logistic processes (static and dynamic context);
- deployment of capital;
- quality of services (process character);
- cost of logistic processes.

Among the metrics in outward bound assessment, the author lists:

- measurement of customer perception;
- benchmarking (comparison of own performance against market leaders).

The authors also argues that effects of processes in a logistic system of the organization may be considered on the three main planes: effectiveness, efficiency, and flexibility.

Multi-criteria cost analyses, relying on a number of parameters, would not facilitate the assessment of the degree of logistic efficiency of the product. One synthetic summary of methods and techniques of efficiency assessment, in the area akin to logistics, i.e. in production, is provided by Koliński[195] who distinguishes five types of production efficiency (understood as the ratio of output to input):

- operational (e.g. productivity growth, cost reduction, loss reduction – optimization of the use of resources – productivity indicator, profitability indicator, activity-based costing);
- market-related (e.g. sales growth – a determinant of market success – indicator – strategic scorecard, customer satisfaction analysis, break-even analysis);
- based on the profit criterion (the only criterion is business profit – MoB (Make or Buy) decision, bottleneck analysis);
- technical (the author defines it as a peculiar case in which a change in outputs induces an inversely proportional change in inputs – SPC (Statistical Process Control), the 5 Whys method);
- dynamic (used to measure the pace of change – the percentage of creative projects, the number of inventions made in the company).

[194] Twaróg J., *Mierniki i wskaźniki logistyczne …*, op. cit., p. 28.
[195] Koliński A., *Przegląd metod i technik oceny efektywności procesu produkcyjnego*, Logistyka, 5/2011, Logistyka – nauka, p. 1085.

As can be seen from the examples presented, efficiency (in the technical sense of the term) has many dimensions for which it would be exceptionally problematic to find a common denominator. Furthermore, the indicators proposed by Koliński are situated on very different levels, which makes their collective application impractical.

The examples provided in the literature clearly focus on measures of the efficiency of logistics processes in an enterprise. They fail, nonetheless, to allow for the role that products themselves have to play, which points to a marked research gap in this area. Therefore, an attempt should be made to build **a model of logistic efficiency of products and its assessment.**

The authors have presented two models of logistic efficiency of the product in the context of product parameters:

- the first one from the standpoint of the organization (Table 9);
- whereas the second one from the perspective of the customer (Table 11).

The model of logistic efficiency of the product in the context of product parameters from the standpoint of the company is comprised of three levels (Table 9).

Level I (the level of the product) corresponds to the development of a new product design or modification of an existing product solely in terms of product parameters, i.e. attributes, properties, and architecture. Since satisfying all of the aspects at once is unachievable, it should be borne in mind that consequences of the modification of attributes, properties, and architecture will reverberate throughout logistic phases and functions.

The influence that the designer exerts over the product (on the level of the product) comes down to the optimization of product parameters – attributes, properties, and architecture. This entails that certain solutions be applied which the review of the body of literature allowed the authors to identify. Performing a general synthesis of the train of thought thus far in the study and of its many threads, it can be established that the designer can optimize the product in three dimensions:

- **attributes**, optimization of:
  - C1 – shape/material;
  - C2 – dimensions;
  - C3 – weight;
- **properties**, optimization of:
  - W1 – vulnerability to transportation, loading and unloading processes;
  - W2 – vulnerability to warehousing and warehouse processing;
  - W3 – packaging amenability (packaging not required, if practicable);

- **product architecture**, optimization of:
  - A1 – standardization/modularity (reducing the number of parts);
  - A2 – multifunctionality;
  - A3 – limiting product configurability[196].

Level II (the level of the process) of design work comes down to thorough analysis of logistic processes, which should make it possible to establish the priorities and set out guidelines for transportability, warehouse-bility, and packaging-ablity. At the same time, considerations of the consequences of product parameter optimization and the guidelines for the three logistic processes in terms of the remaining two elements of the functional classification, i.e. inventory management and order handling, should be taken into account. For the first group of the criteria it may be assumed that transportation and warehousing aspects have many common relations, which paves the way for further classification enabling product optimization for logistics. The designer, therefore, can optimize the product on the level of logistic processes in the following areas:

- transportation-warehousing:
  - optimization by developing standard unit loads and logistic units;
  - optimization of stackability of standard unit loads and logistic units;
  - designing unit loads and logistic units resilient to warehouse-transportation processes (this is consistent with shipping and transportation amenability[197]);
  - designing units that aid the processes of loading, unloading, and warehouse handling;
- packaging:
  - minimization of the packaging compression ratio[198];
  - rationalization of the use of packaging materials;
  - reusable packaging (consistent with the concept of the circular economy).

The second part of the level of the process still remains to be completed, where efforts should be geared towards reducing inventory levels (in the area of inventory management) and maximum streamlining of order handling (in the area of order handling).

Level III (the level of the supply chain) actually provides for a choice of only one of the logistic phases in the supply chain (procurement, production, and distribution). The phase of disposal and returns should be excluded from this particular system because it will operate according to specific guidelines, which will be explained further in the book. The question of

[196] Product parameters related to its architecture ought to be directed at reducing diversity, which Wróblewski saw as reducing, among other things, the range of technological processes. – Wróblewski K., *Podstawy sterowania przepływem produkcji …,* op. cit., p. 14.
[197] Łatka U., *Technologia i towaroznawstwo* …, op. cit., pp. 98-99.
[198] It will be explained further in the study.

integration of the supply chain is also excluded from these considerations because the diversity of industry specific aspects as well as the variability in the composition of the supply chain integration within particular industries can indeed be extraordinary.

Table 9. Model of logistic efficiency of the product in the context of product parameters from the standpoint of the company

<table>
<tr><th colspan="4">I – Product level</th></tr>
<tr><th colspan="2">Flow</th><th colspan="2">Flow organization</th></tr>
<tr><th>Attributes</th><th>Properties</th><th colspan="2">Architecture</th></tr>
<tr><td>C1 Shape</td><td>W1 Vulnerability and amenability to transportation and auxiliary processes</td><td colspan="2">A1 Standardization / Modularity</td></tr>
<tr><td>C2 Dimension</td><td>W2 Vulnerability and amenability to warehousing and auxiliary processes</td><td colspan="2">A2 Multifunctionality</td></tr>
<tr><td>C3 Weight</td><td>W3 Amenability to packaging and packaging</td><td colspan="2">A3 Configurability</td></tr>
<tr><th colspan="4">II – Process level</th></tr>
<tr><th>Transportation / Warehousing</th><th>Packaging</th><th>Inventory management</th><th>Order handling</th></tr>
<tr><td colspan="4">Standard unit loads resilient to warehousing and transportation processes
Packaging not required or, if there is a requirement, then packaging materials – optimum
Packaging compression ratio – min.
Reusable packaging – max.
Low inventory levels (standardization, multifunctionality, limited configurability)
Easy order handling (standardization/modularity, limited configurability)
etc.</td></tr>
<tr><th colspan="4">III – Supply chain level</th></tr>
<tr><th colspan="4">Phase in the supply chain</th></tr>
<tr><th>Procurement</th><th>Production</th><th colspan="2">Distribution</th></tr>
<tr><th colspan="4">Returns and disposal</th></tr>
</table>

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 116.

The criteria summarized in Table 9 are arranged so as to formulate a logical totality of the relations between the individual levels of logistic efficiency of products.

In keeping with the presented track of thought, optimization of attributes and properties, exert its influence mainly in the area distribution logistics (to a lesser extent, in production logistics), on the processes of warehousing, transportation, and packaging as well as on packaging as such. Whereas changes to product architecture will be more meaningful for the spheres of production and procurement and of lesser importance to the sphere of returns and disposal since they typically promote order handling and inventory management processes. That means that designers designing a new product or modifying an existing one and wishing to apply the guidelines provided by Design for Logistics can focus direct efforts depending on the priorities inherent in the individual spheres of the supply chain (procurement, production, distribution, returns and disposal) and logistic processes (transportation, warehousing, packaging, order handling, inventory management).

In keeping with the advanced assumptions, all design activity may be subject to inductive or deductive reasoning. The choice of either path to the design of a logistically efficient product within the framework of DfL will entail certain consequences because it calls for embarking on a search for certain shared solutions which, both from the standpoint of a strategic approach as well as from the perspective of the functional approach, may effectuate a peculiar synergy, i.e. may provide support for product parameters in both contexts, strategic and functional, all at once.

The starting point for the selection of either of the two paths to the process of design is analysis of design amenability of the product because high design amenability does indeed make modification of the product possible but it should rely on a global approach (amenability of systems – deductive reasoning path) or on a process approach (amenability of processes – inductive reasoning path). Low design amenability rules out the possibility of introducing changes other than to processes or systems – Figure 9.

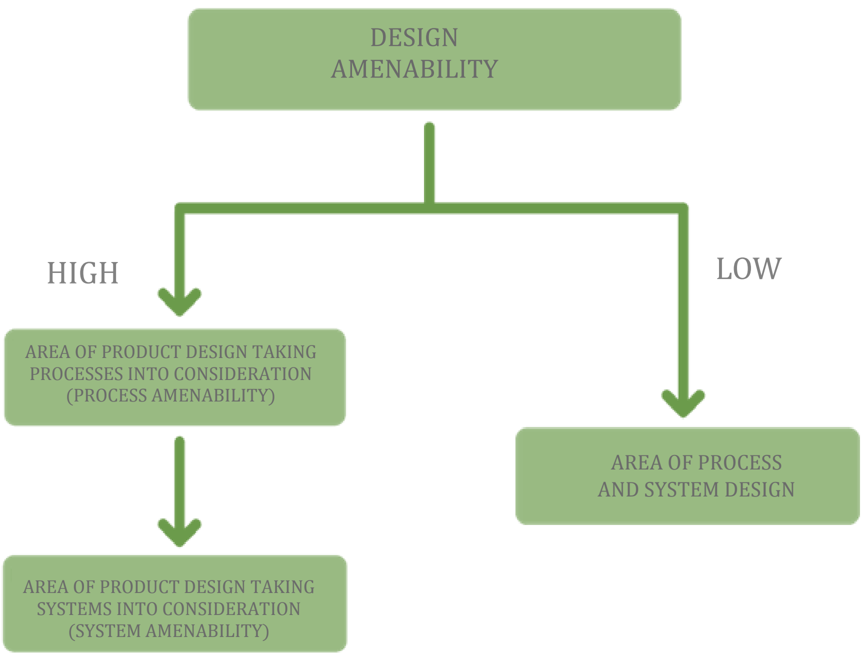

Figure 9. Possible approaches to the process of designing a product or a system, which take design amenability into consideration
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu –projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 117.

The deductive approach should involve systematic and thorough logistic analysis of all stakeholders in the supply chain in order to identify key logistic processes in each of the phases of the supply chain and next, relating them to Level I - the level of the product, i.e. to product attributes, properties, and architecture. If that choice is made for, e.g. the sphere of distribution, then, critical for logistic efficiency will be transportation, warehousing, and packaging processes (and packaging as such), which, in turn, should bear on design efforts to create or modify product attributes or properties in terms of its vulnerability to transportation processes, warehousing processes, and processes related to packaging as a process and a thing. Whereas selecting the sphere of procurement ought to result in focusing on the processes of order handling and inventory management, which should translate into modifications of product architecture. All this shows that the choice of the deductive (global, strategic) level of Design for Logistics will entail certain consequences in terms of the sequence of certain activities. It will tend be geared towards the entire supply chain, while the choice of the functional level will lead to efforts to optimize selected logistic processes – Figure 10.

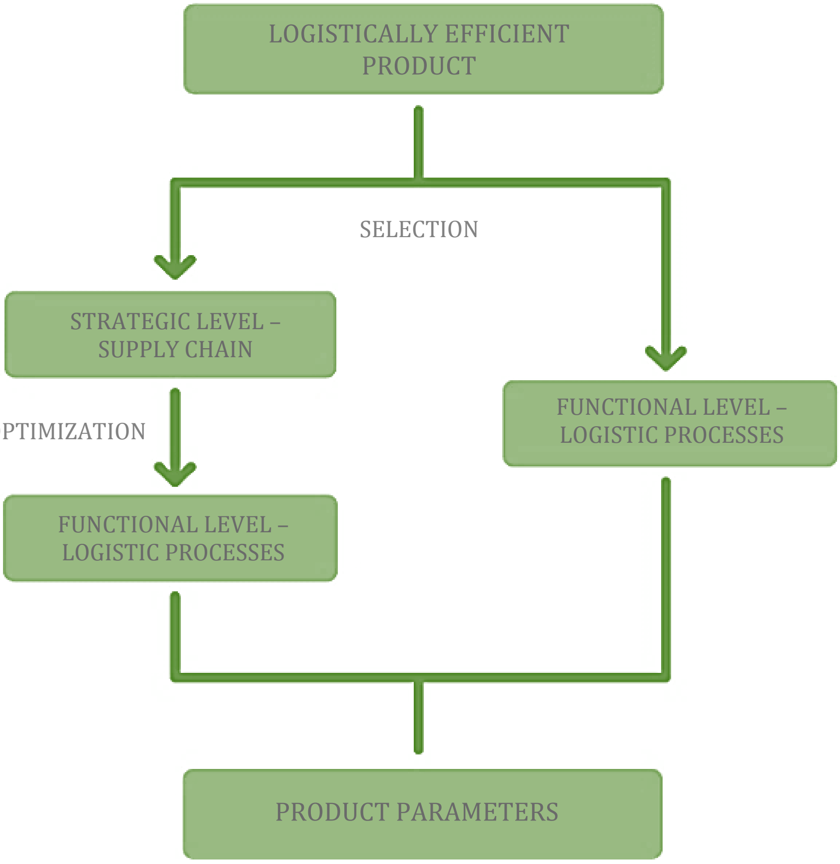

Figure 10. Possible approaches to the design of a logistically efficient product
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 118.

In the deductive approach, attention should be zoomed in on selecting a priority logistic phase in the supply chain to be improved by addressing its idiosyncratic aspects in product design or product modification – Figure 11.

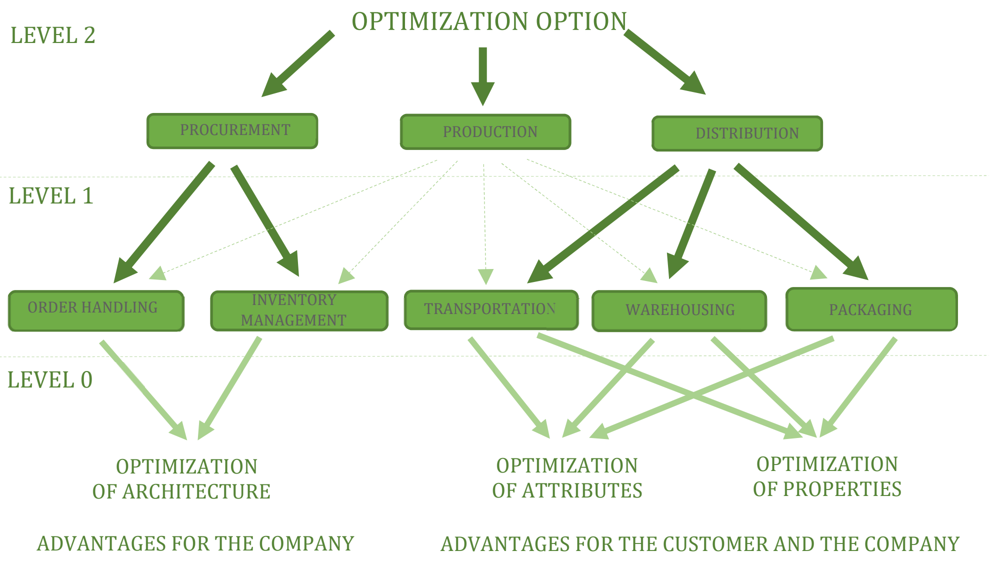

Figure 11. Potential consequences of selecting a variant of product parameter modification in the deductive approach
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 118.

Naturally, selecting a particular logistic phase does not mean having to follow the path delineated by deductive reasoning (Figure 11). This is attributed to the fact that distinctive features of products (regardless of the broad range of assumptions related to the product) as well as the environments in which production companies operate are so dissimilar. That being the case, selecting another logistic process will be reasonable. Nevertheless, it does not change the fact that selecting a particular logistic process will determine the level of the product where design or redesign efforts will be the most advantageous.

Note at this point that the presented approach may be applied to new or redesigned products when design amenability is high or it can be used as a complementary analysis which enables identification of those elements of product parameters that have a considerable impact on logistics.

The choice of product design optimization on Level III (the supply chain) should logically condition the selection of product optimization on Level II by processes which provide the strongest logistic support for each phase, which, in turn, has a bearing on Level I where the job of the designer is to optimize one of the three product parameters: attributes, properties or architecture.

The inductive approach originates from the sphere of potential redesignability of the product with regard to logistic processes. That way, the effect of logistic efficiency of the product will be limited. Subjective analysis performed by the designer points to optimization of transportation, warehousing, and packaging processes in certain logistic phases. The potential of possible changes to product architecture should optimize the sphere of inventory and order handling. This procedure allows the designer to observe logical consequences of their actions and indicate promising areas where the results of introduced design modifications will be salient.

The phase of returns and disposal on Level III has not been considered either in the deductive or the inductive approach. The problem of returns and disposal logistic requires a separate treatment, which is provided further in the book. Its primary goal should be to take end-of-use final products back from the market and reuse them to the greatest extent. From the standpoint of the production company, there are two possible flow paths for used final products and their choice depends on the level of environmental awareness of the manufacturer. The first, passive ("lazy") and decisively simpler, path involves collecting used final products from the market either by a third-party or by the manufacturer and disposing of them. Under those circumstances, product attributes, properties, and architecture are irrelevant to that logistic phase. Product parameters take on a meaningful role if an active, environmental attitude is taken by the enterprise. That being the case, product attributes and properties become critical for reverse logistics transportation and warehousing, whereas product architecture for part and component reuse.

Packaging (noun) is excluded from these considerations, although according to Koszewska and Bielecki, it should progressively be the object of careful analysis in the context of DfL and logistic efficiency of products as an increasingly important element (especially, after the product is purchased by the customer[199])[200].

The premises of the presented model of logistic efficiency of products follow from the analysis of the body of literature on logistics, supply chains, and Design for Logistics. They point out certain potential consequences of earlier design efforts associated with specific design solutions, although it is to be expected that products will appear in which particular design modifications will determine considerably more far-reaching and unpredictable logistic effects. Furthermore, the proposed model does not address the advantages that the application of the DfL

[199] Frequently, getting rid of waste packaging left after the purchase of finished or final is a major challenge – both for retail as well as corporate customers, especially commercial enterprises.
[200] Koszewska M., Bielecki M., *How to make furniture industry more sustainable? The role of component standardization in ready-to-assemble furniture*, Entrepreneurship and Sustainability Issues, Vol. 7, No. 3 2020, pp. 1688-1707.

concept could provide for the final customer, which should indeed be examined. The model of product parameters in the context of its logistic efficiency requires therefore to be embedded within a model of logistics of a production company which supports logistic efficiency of products.

Accepting the presented model of product parameters (Table 9) in the context of its logistic efficiency and the considerations related to the circular economy as necessarily applicable, an opportunity arises to present a simplified model of company logistics which takes into account the question of a logistically efficient product.

A logistically efficient product may be represented with the 5Es rule (easy purchase, easy production logistics, easy distribution, easy return of used products from the market and reuse, easy customer logistics). All of these elements should be incorporated in the model of a production company logistics on which logistic efficiency of the product relies - Figure 12.

On the one hand, a final product or a finished good should have such attributes, properties, and architecture so that it could support and facilitate logistic processes of the company (for the company, it would be logistically efficient), whereas on the other hand, as a unit of sales subject to distribution and processes of return and disposal, so that it could support and facilitate logistic processes of the customer (it would be logistically efficient for the final consumer).

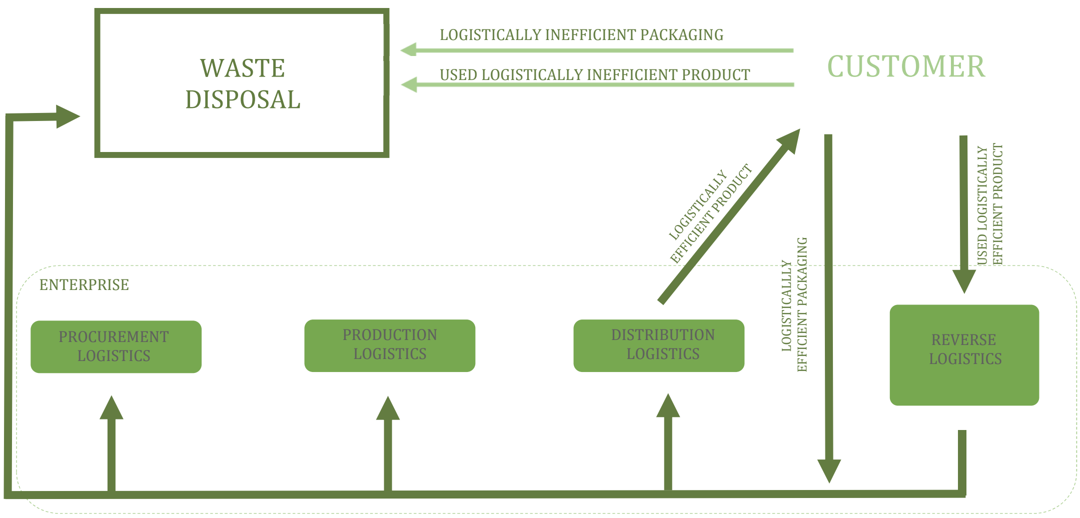

Figure 12. Model of production company logistics underpinning logistic efficiency of products
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 121.

Issues concerning involvement of the customer in the sphere of product logistics as well as of placing the responsibility for reverse logistics on the company further complicate the problem because the fact that the company takes an environmental attitude resulting from closing the cycle for the goods it produces demands that a system of reverse flows integrated with the entire supply chain be established to collect from the market not only used parts and components but also waste packaging.

That means that a company wishing to take an active role in this area must not only build a reverse logistics system (a planned and organized system of collecting waste packaging and used products from the market) but also assess usefulness of the products and packaging taken back from the market in its further operations. Another concern related to this issue is the activity of customers as far as their participation in reverse logistics is concerned, which further expands the scope of the problem.

Thus, the presented model of the logistics of a production company – Figure 12, which is the lynchpin of logistic efficiency of the product, includes a logistically efficient product with its packaging (logistically efficient) as an important element of a logistically efficient product. Since logistic efficiency of the product has already been discussed from the corporate point of view, customer and market considerations regarding logistically efficient packaging and logistically efficient used products will now be discussed.

A logistically efficient product is delivered to the market through distribution processes (leaves the company) and reaches the points of sale. From there on, the customer is responsible for its logistics. Therefore, from the standpoint of the customer, logistic efficiency of the product is associated with the following three main processes:

- delivering the final product to its destination (transportation and, possibly, warehousing processes performed by the customer are central here);
- disposing of the packaging or its reuse;
- effective disposal of the end-of-use final product.

The problem of the packaging of a logistically efficient product may be examined in the context of the two primary processes:

- return;
- disposal.

The process of packaging return compels the company to design packaging (logistically efficient) which would make it possible for the company not only to take it back from the customer but also to reuse it. Certainly, the cost of this kind of a solution would need to calculated. Currently, a majority of industrial establishments are opting for the second path: disposal. Disposal requires no operations on the part of the organization (it is not part of reverse logistics), which leaves it to the customer to get rid of the packaging. That being the case, the packaging will be devoid of the quality of logistic efficiency.

End-of-use logistically efficient product, as the third process on the part of the customer, may or may not be logistically efficient. If it is not logistically efficient, the customer disposes of it in the most convenient way, with the company in no way participating in the process. A somewhat different approach is observed for end-of-use final products that have been designed for logistics because that means that the company is ready to implement a logistic system for the return of used products anticipating their re-entry, in that order, into the stage of distribution (e.g. as spare parts), production (e.g. sub-assembly parts), procurement (e.g. as raw materials and materials), and only at the very end, designating the smallest share of the used product for disposal. Peculiar character of products, their parameters, design amenability, and many other factors may result in a situation when reverse logistics is not practicable. Under these circumstances, the company is left to choose between the path of rationalization or the path of optimization of logistic process.

According to the presented model of the logistics of a production company (Figure 12), if a product is to be analyzed in terms of its logistic efficiency from the perspective of end customers (who can be both households as well as industry operators), the status of end customers should first be clearly defined. Concentrating on households only, the fact arouses no controversy that purchasing consumer goods involves logistic processes associated with transportation, warehousing (storage), and – for the more informed customers, inventory management. Thus, from the standpoint of the customer, the issue of the weight of the finished good and the way it is packaged, i.e. the packaging and its key parameters: materials, dimensions, and weight, come forth as really important.

Nevertheless, observation of day-to-day shopping activities reveals that logistic operations accompanying everyday purchases are much more frequently carried out in relation to products whose weight and dimensions are not problematic for the final customer. For bulkier and heavier products, customers tend to increasingly rely on entities that have the capacity to perform logistic tasks for specific products. Needless to say, research on customer behavior in the context of purchased goods logistics would be very interesting, but it should be treated as further research on logistic efficiency of products. It could be preliminarily assumed that logistic thinking (in terms of transportation, warehousing, and inventory management operations) occurs in those households that are "in the back of beyond". The phrase "in the back of beyond" would refer to the distance from the primary shopping locations starting with increasingly rarely bought press, through bakery items, groceries and household goods, fuel, to occasional purchases of household appliances, home electronics, furniture, and other consumer goods. For this group of customers, optimization of transportation routes (fuel and other products to be purchased while in town), but also stocking up, managing the inventory, and storage play an important role. Therefore, presumably, a greater inclination to carry out purchase-related logistic tasks on one's own should appear.

The second group of customers would represent those to whom transportation, warehousing, and inventory management is absolutely alien because everything is "just round the corner" - inhabitants of big cities and individuals residing close to big city centers. The functions of warehousing and inventory management are taken over by points of sales in the vicinity, whereas the function of transportation, if impracticable by their own efforts, may be commissioned (outsourced) to be performed by third parties (vendor delivery, taxi delivery).

Furthermore, it is worth pointing out that the TSL (Transport/Freight Forwarding/Logistics) sector as well as points of sales, having identified a niche in consumer logistics, exploit it to the full extent by offering a whole range of logistic services related to the purchase of consumer goods. This is attributed to the fact that a larger number of buyers, for various reasons (which, themselves, would be interesting to study) do not wish to participate in the processes of logistic handling (loading, transportation, unloading, placing purchased goods in the right location, etc.) unless it incurs costs that the purchaser would not be able or willing to accept. What follows from this argument is a theoretical model of the end consumer behavior – Table 10.

Table 10. Theoretical model of end consumer behavior as regards logistics

		Logistic attitude	
		Logistic outsourcing	**Logistic self-service**
Type of buyer	**ACTIVE** "**in the back of beyond**"	rarely	**OFTEN**
	PASSIVE "**just round the corner**"	**OFTEN**	rarely

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 124.

The model proposed above makes it possible to raise a perfectly legitimate question of who therefore is to be the beneficiary of logistic efficiency of products from the standpoint of the customer? The answer to this rhetorical question is self-evident. If an enterprise wants to address consumer logistics in the designed product, it is aware that it should think of those customers who wish to "handle the matter on their own", which means they are willing to perform various logistic tasks (and more than that) by their own efforts.

The advanced arguments justify the conclusion that an active attitude of an enterprise to the issue of logistic efficiency of products requires that the customer be also active with regard to the problem in question. That paves the way for a model of enterprise and customer attitudes within the framework of logistic efficiency of products which provides a synthesis of the presented considerations - Figure 13.

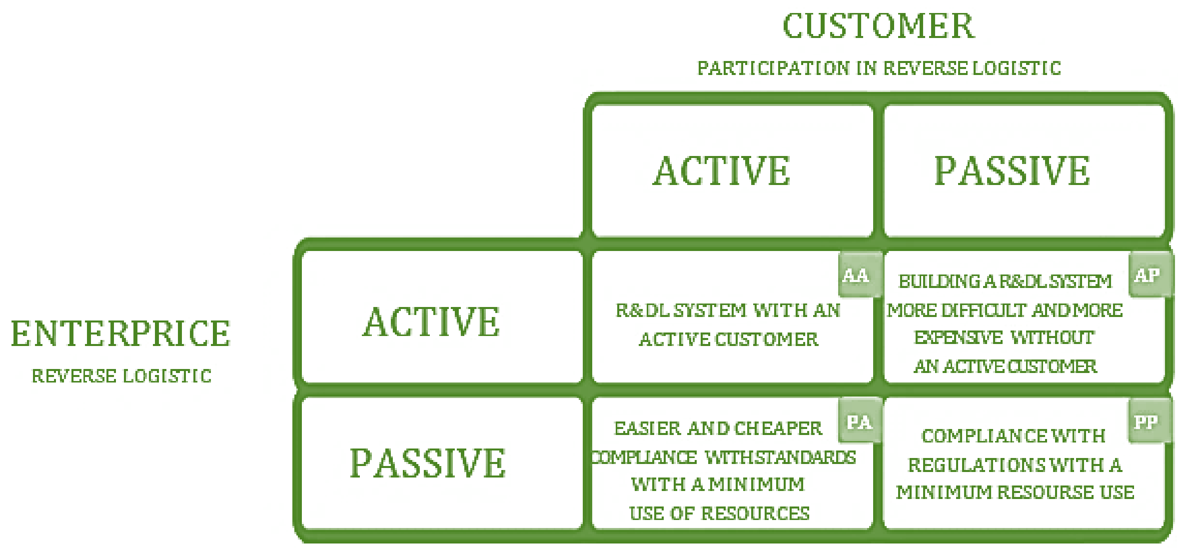

Figure 13. Model of enterprise and customer attitudes in the context of logistic efficiency of the product
Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 124.

The strategic decision for a production company to make will be whether to opt for the active or the passive attitude towards logistic efficiency of the product. Because if the passive attitude is chosen, then, from the standpoint of the company, logistics is treated purely and simply functionally and as such is ruled by time and cost minimization. The company supplies products to the market which reach customers via logistic options available on the market. The active attitude would mean that the company creates products that have been thought out and designed to be able to complete a full cycle and re-enter the market. That being the case, logistics comes forth as a strategic area of its operations, whereas diligence and care to incorporate logistic considerations emerge as a key element of the designer's job.

Involving the customer in logistics is an important feature of the described system. Customer participation must be rewarded with certain benefits (e.g. product is readily available off-the-shelf, comes at a good price, potential logistic tasks allow the customer to save resources, to economize). It entails the performance of certain logistic actions associated with purchasing, getting rid of the packaging at the stage of the purchase, and/or disassembling a used product and forwarding the disassembled parts to the sphere of reverse logistics of the company – **alternative AA – Logistic symbiosis –** in the phase of returns and disposal. For this alternative it is assumed that the return of a used final product may be easier if a proactive attitude is adopted. A situation is then within the bounds of possibility where the company provides the product not only with assembly instructions (if required), or an owner's manual, but also with instructions on how to handle a used product explaining to the customer e.g. how to disassemble it and what exactly to do with the disassembled parts. Naturally, customer motivations for this type of actions are disregarded as a separate area of consumer research.

When an active attitude towards logistic efficiency of the product on the part of the company is coupled with a passive attitude of the customer (**alternative AP – logistically advantageous purchase**), logistic efficiency of the product essentially makes the logistic process of purchase easier for the customer. Thus, it brings an advantage, some additional value, for the customer, although the function related to the circular economy is excluded from the activity of the company. With a passive attitude of the customer and an active attitude of the enterprise, the problem of getting rid of a used final product is solved in a way that is the most convenient for the customer, which may have certain unpredictable consequences for the enterprise. Under such circumstances the system may start "leaking", with a tangible effect of that leak being a smaller percentage of parts and/or raw materials that could represent new input into the production system[201] returning to the company.

The situation in which a passive attitude to logistic efficiency on the part of the company coincides with passive disposition of the customer represents the **PP alternative**. Here, the company, for a variety of reasons, does not regard including logistic efficiency of products in product design as advantageous (one reason could be low logistic amenability of the product), whereas the customer treats logistic tasks as a necessary evil – minimization of the cost of logistics on the part of the customer.

The last of the analyzed variants (**alternative PA**) has been termed **logistic immaturity**. Here, customers want to follow a proactive approach to logistics but the disregard for Design for Logistics, leading to the availability on the market of logistically flawed products, fritters away the potential for benefits that could be derived from the market.

[201] A more extensive discussion of the topic is provided in the article submitted for XXI IGWT Symposium – Sustainability, Quality and Innovation: A Global View of Commodity Sciences, Roma Tre University: Koszewska M., Bielecki M., *Product circularity performance and consumer attitude as key determinants of the effective implementation of the circular economy model. The case of furniture industry.*

The presented models show clearly that the only determinant of developing particular practices for product design should be the company's active attitude to logistic efficiency of the product. Both packaging design, in view of its reuse or recycling, as well as selecting particular product parameters to be rationalized with regard to reverse logistics are important elements of the company operations. Nevertheless, with reference to the nine elements of logistic design amenability (Table 9), it should be noted that only product architecture, in terms of standardization and multifunctionality of parts, provides the company with the capacity to develop the logistics of returns and disposal.

The second of the proposed models is a **model of logistic efficiency of the product in the context of product parameters from the standpoint of the customer**.

This is where an attempt should be made to establish which parameters from the model of logistic efficiency of the product in the context of product parameters will be relevant for the customer. In accordance with the model of logistic efficiency of the product, product parameters are divided into three main groups; attributes, properties, and architecture. From the viewpoint of the purchase-related logistics performed by the customer (irrespective of whether logistically active or passive), each of the nine detailed product parameters will be of somewhat different importance to the customer, as shown in Table 11.

Table 11. Model of logistic efficiency of the product in the context of product parameters from the perspective of the customer

<table>
<tr><td colspan="5">I – The level of the product</td></tr>
<tr><td colspan="3">Flow</td><td colspan="2">Flow organization</td></tr>
<tr><td>Attributes</td><td colspan="2">Properties</td><td colspan="2">Architecture</td></tr>
<tr><td>C1 Shape</td><td colspan="2">W1 Vulnerability and amenability to transportation and support processes</td><td colspan="2">A1 Standardization / Modularity</td></tr>
<tr><td>C2 Dimension</td><td colspan="2">W2 Vulnerability and amenability to warehousing and support processes</td><td colspan="2">A2 Multifunctionality</td></tr>
<tr><td>C3 Weight</td><td colspan="2">W3 Packaging</td><td colspan="2">A3 Configurability</td></tr>
<tr><td colspan="5">II – The level of the purchase process</td></tr>
<tr><td>Transportation / Warehousing</td><td colspan="2">Packaging</td><td>Inventory management</td><td>Order handling</td></tr>
<tr><td colspan="5">III – The level of the customer supply chain</td></tr>
<tr><td colspan="5">Phases in the supply chain</td></tr>
<tr><td colspan="2">Distribution</td><td colspan="3">Returns and disposal</td></tr>
</table>

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 126.

As previously assumed, customer engagement in the logistic aspect of purchase is associated with the two primary issues: transportation of the purchased product and the packaging of the purchased product as it has a real impact on the transportation process. Both of them involve physical movement of the purchased goods from the point of purchase to the destination site. Therefore, regardless of which attitude the customer adopts (active - passive), crucial for the process are attributes such as product weight as well as the parameters of the packaging. It follows that the question of C1 (shape and material) is of secondary and lesser importance when it comes to logistic efficiency of the product. Whereas product dimensions (attribute C2) and product weight (attribute C3) have an indirect impact on purchase logistics. It is the weight that determines the effort required for handling the product such as loading and unloading, while the size of the final product (length × width × height) indirectly affects the dimensions of the transportation unit of the product[202].

Examining properties, it is important to note that the transportability and warehousability will be considered by the customer from a somewhat different perspective than was the case for the production company. As previously stated, the idea of logistic efficiency of the product in a manufacturing company will tend to be realized by designing unit loads which enable effective movement of goods in the distribution sphere, whereas from the customer point of view, the unit of sales and the parameters of its packaging will be more important. Consequently, when optimizing unit loads, the company should take into account transportability of units of sales – parameter W1 – transportation amenability and parameter W2 - warehousing amenability. The W3 parameter can only be considered here in the context of the packaging which, as previously argued, is an important element of purchase logistics.

The last of the aspects, concerning architecture, also has an indirect impact on purchase logistics. Standardization (parameter A1) of the product architecture as well as multifunctionality (parameter A2) remain practically irrelevant for the customer, while modularity may increase product appeal. The same is true of parameter A3 – personalization, which can also contribute to the attractiveness of the product.

[202] Transportation dimensions should be determined for at least one of the listed parameters.

3. CHALLENGES IN RESEARCH ON LOGISTIC EFFICIENCY OF THE PRODUCT

3.1. Measuring logistic efficiency of the product

The overall data concerning product parameters in the model of logistic efficiency demands that at least several aspects be addressed related to methodology for logistically efficient products that pertain to:

- establishing the assumptions and guidelines for conducting research in this area;
- defining the main metrics and indicators based on the assumptions and guidelines for carrying out the research;
- providing approaches to the process of design which aids logistics and creates logistically efficient products.

Establishing guidelines and assumptions for research on logistic efficiency of products requires that the complexity of the issue be taken into account, and, from the very beginning, reveals the difficulty in selecting objects of study, which stems from the diversity of products available on the market. The second very important consideration is the question of access to data concerning product parameters, where product parameters related to attributes hold the greatest potential for data collection (C2 – size; C3 – weight), while the parameters related to properties and architecture are considerably harder to obtain from any enterprise.

The identification of the objects of research means that companies that actually apply DfL in their practice need to be identified. It may however be the case that the companies do indeed follow the DfL principles without being able to properly name the applied approach. In these circumstances, it could be useful to do the reverse, i.e. to identify products on the consumer goods market which to a large extent comply with the assumptions for logistically efficient products. Following from there, the company that offers these products may be identified as a reference company. Furthermore, it would be highly useful to obtain reasonably unrestricted access to data concerning the parameters of the product, as this would facilitate the research. Clearly, another important factor is the design amenability of the products provided by the company. High design amenability of products warrants the possibility to observe engineering modifications. Consequently, further research makes it possible to identify a greater *spectrum* of determinants of logistic efficiency of the product. Analysis of the reference object of research additionally entails a comparative analysis to other companies in related sectors of the industry, in which access to data on product parameters would also be unhampered.

The selection of objects for a comparative analysis should begin with an appraisal of the research potential related to the possibility of unconstrained access to synthetic data related to the parameters of the product as defined in the model of logistic efficiency of the product. As a result, data concerning the reference object and sector-related objects with the highest research potential could be aggregated, which would eventually result in the analysis of research results. However, in order to be able to analyze research results, a set of analytical measures for the model of logistic efficiency of the product is prerequisite. The measures should enable effective measurement and analysis of the subject matter.

The definition of the units of measurement of logistic efficiency of the product should follow the model of logistic efficiency of the product with respect to the parameters of the product from the perspective of the company – Table 9. The first parameters represent the three principal attributes of which the first one – C1 – shape/material, is strictly qualitative, while C2 (dimensions) and C3 (weight) are quantitative.

The analysis of the C1 attribute – shape/material, may be performed on at least two planes. The first concerns the shape, i.e. the determination of the spatial geometry of the final product and of the implications that arise from that for unit loads and logistic processes. The second one, pertaining to the material, would require further analyses in terms of materials science and engineering which would help to evaluate whether the one material would be preferable to other materials. The research potential of this parameter, in terms of materials engineering, is not particularly high, since it requires either specialized knowledge, as is the case for materials analysis, or additional research on the effect of certain shapes on logistic processes. Nevertheless, it does help to identify the group of the most common materials, and perhaps their relationship with the weight of the product including the packaging, which is rather relevant from the standpoint of logistics.

In the case of shapes and forms, the analysis could be simplified by pointing out that the regular hexahedron (cube) and rectangular prism (cuboid) are the most common types of unit loads. Thus, research on logistic efficiency of the product could proceed from this type of solids. As regards the shape of the product, consideration should also be given to eventual disassembly of the final product, as an important element influencing the design of logistically efficient products. The issues of the potential measurement of disassembly are most common in the field of design for disassembly and very often, they are based on recycling indicators[203] or on

[203] Villalba G., Segarra M., Chimenos J.M., Espiell F., *Using the recyclability index of materials as a tool for design for disassembly*, Ecological Economics 50, 2004, pp. 195-200.

advanced mathematical algorithms[204]. Basing the analytical tools for logistic efficiency of the product on such indicators would mean that the problem would have to be extended once again to include new areas which, according to the authors, would lead to the emergence of new boundary conditions which would hinder concluding the model with one synthetic study. Rather than resorting to complex mathematical formulas, a simple parameter can be used that reflects the type of material used to manufacture a particular product or the number of assembly operations performed by the operator to restore the product to its final form. Any such parameter would have to be described as an indirect measure, which would make it possible to refer to e.g. the packaging in the further part of the study.

Materials analysis of a product could only give some insight into the issue if it could be captured and proven that:

1) there have been changes in the use of materials in the final product over the years;
2) these changes have been triggered by logistic considerations.

To be able to carry out this kind of research, access to the historical parameters of the product is often necessary, which implies that generational research involving detailed data on the materials used and expertise in materials engineering would be required.

The attributes concerning the dimensions and weight represent a relative quantitative element. This element, set against e.g. the weight and dimensions of the packaging, helps to identify certain distinctive features of logistic efficiency of the product. The metric that enables analysis of the collected data may be the metric of the cubic capacity of the product (*Wkp*) (the metric of the volume), which is calculated as the product of the length, width, and height of the final product - Formula 1.

$$Wkp = length\ x\ width\ x\ height\ (cm^3) \qquad (1)$$

Consistency and repeatability with respect to the materials used and the dimensions of the final products (directly impacting on unit loads) allow all stakeholders in the logistics chain (including end customers) to specialize to such an extent in the logistic processes and their organization that the efficiency and effectiveness of these processes should improve.

The volume metric can be combined with the product weight to give a cubic capacity to weight ratio. The cubic capacity to weight ratio (*Wkw*) can indicate the cubic capacity of the finished good expressed in cm^3 per kilogram of the product - Formula 2.

[204] Cappelli F., Delogu M., Pierini M., Schiavone F., *Design for disassembly: a methodology for identifying the optimal disassembly sequence*, Journal of Engineering Design, Vol. 18, No. 6, 2007, pp. 563-575.

$$Wkw = \frac{length\ x\ width\ x\ height\ (cm^3)}{the\ weight\ of\ the\ finished\ good\ (kg)} \quad (2)$$

The higher the value of this indicator (1 kg will take up a larger space, e.g. polystyrene foam), the less advantageous it is from the point of view of optimizing logistic processes of transportation and warehousing (movement and storage of the product will be problematic due to the sheer volume of the product). The lower the value of this metric, the more important it will be to consider the mass of the load as a critical factor in the processes of transportation and warehousing. What follows is that the cubic capacity to weight ratio will have certain optimal parameters for certain products in certain sectors of the industry.

The second category of parameters corresponds to product properties. Investigation of product properties involves gathering data on transportation and warehousing amenability, the process of packaging, and the packaging.

As previously stated, units of measurement have already been proposed for transportation and warehousing amenability, e.g. Bogdanowicz[205]. Examining and analyzing the issue of transportation and warehousing amenability for a selected group of products by applying complicated algorithms could be an uphill task. One might even assume that the final output of this effort would not generate a finite number of generalizations, but would only expand the scope of the presented study by adding another strand. Since these issues are certainly relevant to the model of logistic efficiency of the product, an assumption is made that parameters W1 (vulnerability and amenability to transportation) and W2 (vulnerability and amenability to warehousing) will be considered solely and exclusively by the criterion of data accessibility. That means that, in reality, the degree to which information concerning the transportation and warehousing practices employed by the company is made available will determine the extent to which this information is used in the study.

The scenario is somewhat different with respect to the W3 criterion - packaging amenability and the packaging itself. Indeed, the analysis of the way products are packaged, the placement of individual elements of the final product or the whole final product in the packaging, account for the cubic capacity of the packaging itself. It was therefore concluded that the parameters of the packaging such as dimensions (length, width, height), weight, the number of packaging pieces make it possible to determine the total cubic capacity of the packaging according to Formula 3 - a metric of the cubic capacity of the k-piece of the packaging - (Wkc_O).

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[205] Bogdanowicz S., *Podatność. Teorie i zastosowanie w transporcie …*, op. cit., p. 38.

$$Wkc_O = length\ x\ width\ x\ height\ (cm^3) \quad (3)$$

The sum of the Wkc_O of all pieces of the packaging makes it possible to establish a metric of the cubic capacity of the packaging of a single product (*Wkc*) described with Formula 4.

$$WKC = \sum_k^n Wkco_k\ \ (cm^3) \quad (4)$$

The metric of the cubic capacity of the packaging alone can only provide information about the spatial size of the packaging. Whereas combined with the analysis of the dimensions of the packaging it may enable a simulation of unit load formation, which would in some way reveal transportation and warehousing amenability of the product. Unfortunately, it would also require information technology tools to aid in the simulations, and the range of data analyzed would be quite vast.

Therefore, the authors have decided to devise the packaging compression ratio (*Wko* – Formula 5) to reflect the relation between the cubic capacity of the final product and the cubic capacity of its packaging.

$$Wko = \frac{Wkc}{Wkp} \quad (5)$$

Clearly, the lower the *Wko* ratio, the higher the transportation amenability in terms of the load for the company and consequently for the customer (as long as it is positively correlated with the weight of the product). As the product attributes are maximized (dimensions and weight become larger, and the shape grows in complexity), the *Wko* ratio assumes greater significance as a central element of logistics.

The packaging compression ratio also reveals a certain relationship concerning transportation and warehousing amenability. The lower the packaging compression ratio, the greater the degree of standardization of the unit loads should be. The most obvious illustration for this assumption is provided by bulky, high-volume consumer goods (furniture, washing machines, refrigerators), which allow for the possibility of involving the end customer in the logistic processes. Large household appliances, as the product category is referred to, which include washing machines and refrigerators, are characterized by a small number of assembly operations performed by the person who assembles the product into the finished good.

Furniture, in many cases, is disassembled to the point where the packaging compression ratio should be relatively low, which naturally depends on the design of the final product, furniture being the case in point. Furniture therefore exhibits a much higher design amenability compared to washing machines or refrigerators, and the packaging compression ratio should be relatively constant, regardless of the manufacturer. The reason lies not only in the standardization of these products (e.g. dimensions, type of materials used, etc.), but also in the limited number of assembly operations carried out during the handover of the product for end-use.

Accordingly, household appliances that are standardized to a much greater degree must compensate for low logistic design amenability through optimization of logistic processes, which is consistent with the assumptions made in the preceding chapters. For furniture, the range of solutions to support logistic efficiency of the product on the part of the consumer, but also on the part of the company, is much greater because furniture features a higher potential for design amenability which is also affected by the degree of disassembly of the final product delivered to the customer.

Evidently, such an approach dictates an active attitude of the customer. Equally interesting from the point of view of logistic efficiency of the product is customer self-service in the realm of logistics. It helps to move the point of customer engagement not only towards logistic processes, but also towards other, additional tasks such as assembly, disassembly, packing and unpacking, which can further support logistic processes. Certainly, this type of performance requires an underlying inducement, which frequently means lower purchase costs and other kinds of incentives. However, it does appear that logistic self-service by the customer unlocks a potential which needs to be considered in researching logistic efficiency of the product. It is worth emphasizing that customer self-service, i.e. customer engagement in product logistics, will only pertain to two phases of the supply chain, i.e. distribution logistics and returns and disposal logistics. Consequently, it is only in these areas that the customer can be involved in logistic operations.

This leaves the last group of parameters in the model of logistic efficiency of the product concerned with product architecture to be examined. The first of the parameters, A1 – standardization (which is part of product architecture), will be linked to the use of standard elements in final products. The greater the degree of repeatability of these elements, the more advantageous the impact on logistic processes and logistic chain is expected to be. This could start with the assumption that the more structurally similar products are, the higher a certain indicator of standardization ought to be. Needless to say, a high degree of standardization for all assortment groups would be ideal but that would require a determined engineering effort.

To measure the degree of standardization, the authors have proposed two main indicators based on the methodology of the approach to the measurement of standardization, i.e. the rate of:

- standardization (*Wks)*;
- standardization saturation (*Wns*).

One more indicator has been introduced – the rate of standardization detection *Wd*. Formula 6 describes the number of duplicate component parts in a particular product group. Note that the rate of standardization detection only indicates that standardization occurs, however, it does not provide any qualitative information about it.

$$Wd = \frac{The\ number\ of\ component\ parts\ less\ duplicates}{The\ sum\ of\ component\ parts} *100\% \qquad (6)$$

Qualitative changes in standardization can be illustrated with the rate of standardization (Formula 7) and the rate of standardization saturation (*Wns*) – Formula 8. The rate of standardization (*Wks*) indicates the percentage share of the number of times one component part occurs in a particular group of products.

$$Wks = \frac{The\ number\ of\ times\ a\ component\ part\ occurs\ in\ a\ product}{The\ total\ number\ of\ products} * 100\% \qquad (7)$$

Assuming that the number of component parts less the duplicates is entered into columns, and that each row corresponds to a particular final product, the number of fields at the intersection of rows and columns will represent the number of instances that part is used in the product. Thus, the indicator may be presented graphically as a matrix in which the darkened fields marked with an integer (representing the instances a given part occurs in a given product) will be contrasted with the fields that are not darkened, i.e. those for which such a relation does not hold. The ratio between the two sets of fields indicates the rate of standardization saturation *Wns*.

$$Wns = \frac{The\ number\ of\ cells\ where\ the\ part/product\ relation\ holds}{The\ total\ number\ of\ cells\ in\ the\ matrix} * 100\% \qquad (8)$$

The indicators for standardization are, in a sense, related to the solutions which have already been available. In their study *Design for variety,* Martin and Ishii[206] drew attention

[206] Martin M., Ishii K., *Design for variety: developing standardized and modularized product platform architectures …*, op. cit., pp. 213-235.

exactly to the issues of part standardization and modularity. They proposed spatial and generational variety indicators, the underlying reasoning of which was, in a certain sense, similar to that applied to the indicators presented here.

Besides standardization and modularity, there are two other elements in the group of parameters associated with product architecture: the first relates to multifunctionality. Multifunctionality can be measured as the percentage of the multifunctionality repeatability - *Wpm* – Formula 9.

$$Wpm = \frac{The\ number\ of\ parts\ used\ for\ at\ least\ two\ different\ functions}{The\ total\ number\ of\ parts} * 100\% \qquad (9)$$

The rate of multifunctionality indicates how prevalent the use of a given part for completely different functions is (e.g. in one application, the screw is used as a fastener, in another application, the same screw is used as a fixing element).

The second element in the group of product parameters associated with its architecture concerns configurability (personalization). From the perspective of logistics, configurability should possibly manifest itself in two conflicting goals:

1) providing the customer with the greatest possible choice (personalization);
2) ensuring the narrowest possible product assortment for the company, which leads to standardization and repeatability of logistic operations (the idea of mass customization)[207].

From the standpoint of a pragmatic approach to logistics, the two objectives are contradictory, which means that the range of product options available should be relatively steady or should decrease, while the customer should be able to have a choice.

The trend for manufacturers should be to change their assortment items *in minus* or to keep them at a relatively minimal, steady level.

In addition, the amenability to the organization of the physical flow of the product relies on order handling and inventory management processes. The determinants of these processes are related to the sphere of organization and management rather than to the sphere of infrastructure, as well as to the sphere of product architecture. Improving order handling processes with a view to simplifying them, but also rationalization of inventory-on-hand with a view to keeping it to a minimum, are the most important challenges for this category of amenability. It will however strongly depend on consumer expectations coming from the market.

[207] Anderson D., *Agile Product Development for Mass Customization*, McGrown-Hill, New York, 1998.

That means that the greater product assortment and product diversity is demanded on the market, the more difficult order handling and inventory management processes are likely to become.

Whilst this assumption would be valid as long as assortment and product diversity required the development of highly personalized products made from customized components and job (one-off) production. Consequently, the greater the degree of standardization in the architecture of products and assortments, the easier it should be for a company to organize and manage its inventory and customer service.

The complexity of logistic processes as well as of the factors determining the functioning and characteristics of supply chains preclude any attempt to relate the discussed issue to a quantitative assessment of efficiency due to a lack of relativism involved in such an assessment. Increased transportation efficiency may lead to a decline in order handling and inventory management metrics, which makes it difficult to ultimately measure the degree of logistic efficiency. Nevertheless, the whole concept ought to serve the purpose of reconsidering the role of product design in logistic processes and the relationships between product parameters (attributes, properties, architecture), logistic processes, and logistic phases.

A very important role in logistic efficiency of products would be served by the analysis of its effectiveness with respect to logistics and the supply chain. It would, however, require such a large amount of data and information from companies that the risk of not being able to collect it could indeed be real.

Research on logistic efficiency of the product is complex. One reason for this comes from the fact that many fields of knowledge, from design to logistics, supply chains, quality, production, and customer behavior, are brought to bear on the problem. The number and variety of products offered on the market, which most probably constitute a closed yet a very large set, does not help the matter, either.

Studies on logistic efficiency of the product are further complicated by varied market conditions. Starting, for example, with a marketing approach to the product, in which, among other things, the marketing mix (Product, Price, Promotion, Distribution), or its variants,[208] has a decisive effect on the purchasing behavior of consumers, and ending with e.g. organizational factors involving company consolidations or buy-outs part of global corporate mergers and acquisitions. That leads to a continuous variability in the products offered and changes in the specifications of product parameters. The aforementioned ownership instability of product

[208] Penc J., *Encyklopedia zarządzania. Podstawowe kategorie i terminologie,* Wyższa Szkoła Studiów Międzynarodowych w Łodzi, Łódź, 2008, pp. 412-414.

brands renders it particularly difficult to keep track of the prerequisite considerations for product design and development.

Nor does it help that DfX methods, such as Design for Logistics, are applied much less frequently than other approaches which are geared towards cost optimization, e.g. design for manufacturing or design for assembly, and which, from the viewpoint of production companies, offer entirely different benefits. Production companies very often objectify logistics and logistic processes treating them as operations that are primarily subject to cost minimization.

Another, and at the same time very meaningful limitation, is unrestricted access to all kinds of data concerning product details (product parameters), which, by virtue of know-how protection, involves a formalized and bureaucratic procedure of filing written applications and awaiting feedback concerning access to data from the various levels of management. The conclusion following from these arguments is that in order to investigate logistic efficiency of products, one needs to find companies which not only apply Design for Logistics but also have a system of information about their products and the changes introduced in the products, to which there is unrestricted access.

Finally, research should target products whose design is highly amenable logistically and, at the same time, incorporates solutions based on the DfL concept. By extension, one must be able to perform product analysis but also track changes in particular periods to identify product optimization trends, which would prove that logistics, or essentially its phases and processes, are relevant for the company.

With so many variable elements and so many constraints, it has been concluded that in order to open a scholarly discourse both on logistic efficiency of the product and on Design for Logistics it would be productive to begin with the company that has been the inspiration for taking up that topic in the first place.

3.2. The concept of a research method for logistic efficiency of the product

Given the fact that the overall idea originated with a company involved in the design and distribution of furniture, it has been decided that the choice of this type of goods for research will be well founded. Certainly, furniture is a relatively simple final product and therefore, the selection may perhaps provoke criticism as being far removed from any contemporary finished good used by humans on a daily basis in 21st century. This argument can be refuted with a single explanation. The deliberate choice of the objects of study marks the beginning of scientific research on the issue of logistic efficiency of the product and the concept of Design for Logistics. For there is a very considerable risk that the selection of more complex research objects would lead to a stalemate in the entire research process.

Logistic efficiency of the product can be investigated with a variety of methods whose overriding goal is to achieve either qualitative or quantitative results. However, based on the proposed theoretical model as well as the presented example, the authors have decided to employ case survey and case study as one of many qualitative methods (or non-probability research strategies[209]), which represents an idiographic approach aimed at presenting and explaining particular (individual) facts and events[210].

Bendkowski and Dohn's work is a very useful baseline reference which keeps the particularities of research on logistics in view, although on a somewhat different level (mainly dissertations) – especially with regard to defining research questions and methods for investigating logistic processes[211]. The research proposed by the authors, nevertheless, required that the review of literature concerning this topic be further expanded.

As early as in 1996, Ellram[212] demonstrated how the case study approach could be used for research on purchasing and logistics. In her study, she used a simple table - Table 12, to classify research methods based according to key research objectives and questions posed[213].

Ellram argued that *case study* provided for an excellent method in the field of logistics to do research on:

- implementation and applicability of Artificial Intelligence and expert systems in logistics;
- understanding the impact different types of logistics have on organizational structures with respect to the role of logistics in the organization;
- understanding the decision-making process involved in outsourcing logistics operations;
- developing a theory concerning the impact of material flow management as an important area of management in the company[214].

Table 12 provides a clear picture of a group of objectives related to exploring and explaining centered around the questions of how and why. Among the qualitative methods used to explore the issues under consideration, case survey and case study[215] appear to be appropriate at this stage in the research.

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[209] Dul J., Hak T., *Case Study Methodology in Business Research …*, op. cit., pp. 3-6.
[210] Matejun M., *Metoda studium przypadku w pracach badawczych młodych naukowców z zakresu nauk o zarządzaniu,* Zeszyty naukowe Uniwersytetu Szczecińskiego, nr. 666, Problemy Zarządzania, Finansów i Marketingu, Nr 19/2011, p. 204.
[211] Bendkowski J., Dohn K., *Logistyka. Pisanie pracy dyplomowej, kwalifikacyjnej. Zasady pisania, studia przypadku …*, op. cit., pp. 41-54 and pp. 105-179.
[212] Ellram L., *The use of the case study method in Logistics Research …*, op. cit., p. 93.
[213] Ibid., p. 98.
[214] Ellram L., *The use of the case study method in Logistics Research …*, op. cit., p. 115.
[215] For more information on the case study, see: Strumińska-Kutra M., Koładkiewicz I., *Studium przypadku*, [in:] Jemielniak D., (ed.), *Badania jakościowe*, *Metody i narzędzia.* Tom 2., PWN, Warszawa, 2012; Eisenhardt K., *Building Theories from Case Study Research,* Academy of

Table 12. Classification of research methods by key research objectives and questions posed

OBJECTIVE	QUESTIONS	Examples of appropriate methodologies
Exploration	How? Why?	**Qualitative:** experiment case study participant observation
	Hoe often? How many? How much? Who? What? Where?	**Quantitative:** survey questionnaires secondary analysis of data
Explanation	How? Why?	**Qualitative:** experiment case study participant observation grounded theory case survey
Description	Who? What? Where? How many? How much?	**Quantitative:** survey questionnaires secondary analysis of data
	Who? What? Where?	**Qualitative:** case study experiment grounded theory case survey participant observation
Prediction	Who? What? Where? How many? How much?	**Quantitative:** survey questionnaires secondary analysis of data
	Who? What? Where?	**Qualitative:** case study experiment grounded theory case survey participant observation

Source: compiled by the authors based on Ellram L., The use of the case study method in Logistics Research, Journal of Business Logistics, vol. 17, no. 2, 1996, p. 93.

Management Review, Vol. 14, No. 4, 1998, pp. 532-550; Flyvbjerg B., *Five Misunderstandings about Case-Study Research*, Qualitative Inquiry, Vol. 12, No. 2, 2006, pp. 219-245.

It follows from the deliberations in the previous chapters that the key aspect of logistic efficiency of the product lies in the parameters of the product, i.e. its attributes, properties, and architecture. Therefore, when looking for a rationale for the design of logistically efficient products and trying to delineate the scope of the application of the Design for Logistics concept, it would be appropriate first of all to investigate any relations and dependencies in this respect. However, this requires a range of product information that could be obtained at any time. Since the model of logistic efficiency of the product, on Level I - the level of the product (Table 9), determines the elements which fall within product attributes, properties, and architecture, consideration should be given to what data needs to be collected and to what extent it is obtainable from the company.

Therefore, before the process of research is designed, theoretical parameters of the product need to be set against obtainable data and information about the product. Not until this has been done is it possible to determine the scope of the investigation. Consequently, the first step is to describe product parameters in detail with respect to their research potential and the possibility to formulate final conclusions, and to relate them to the model of logistic efficiency of the product.

In the presented model of logistic efficiency of the product in the context of product parameters from the perspective of the company (Table 9), product attributes are described with three main parameters: the shape (material) of the product, its primary dimensions, and its weight.

To investigate **the shape of the product combined with the materials** used to make it is a major challenge. From the vantage point of commercial and logistic facilities, the most optimal shape of the final product or sales unit of the final product would be a cube or cuboid, a multiple of which would fill a standard pallet up in terms of its area and height, creating the appropriate volume of 1200×800×Y (Y varies depending on the requirements of transportation and warehousing processes). The recommended dimensions of unit loads have been formulated on that basis, e.g. those set out in the Polish standards[216]. Any other shape requires an appropriate packaging that should also be a cube or cuboid. Examining products for this purpose (to determine whether or not the product is a cube or a cuboid) is feasible as long as the relevant data is readily available. The situation becomes more complicated for products with complex

[216] PN-O-79021:1989 – Packaging – System of dimensions – Scope: The standard regulates packaging with rectangular and circular section. General requirements for the dimensions of transport packages and unit loads are specified. Examples of stacking packages on pallets are given. The formula to calculate the dimensions of unit loads is provided.

or round shapes. At that point, the multitude of logistic solutions for both products and product packaging essentially form a separate research topic.

The question of **materials** used in products is even more problematic. As it turns out, while it would be possible to get information about the materials used in a product, the level of detail provided may raise concerns. For example, specifying that a given piece of furniture is made of fiberboard or particleboard unfortunately provides the customer with only general information about the material used. The number of layers, the density, the degree of sizing, the shape and size of the chips, etc. are not typically made publicly available by the manufacturer. There are at least two reasons for this. The first, related to the consumer, is based on the assumption that customers would not really want this type of detailed information (and, as a matter of fact, it would be absolutely useless to them). The second, linked to running the risk of know-how disclosure, of possible competitive rivalry. Nevertheless, if anyone wanted to explore this parameter (material), detailed information on the material in question would be indispensable, as would highly sophisticated knowledge concerning the different areas of materials science and engineering.

Questions about the materials from which the product is made do, however, make it possible to search for relations between changes in the materials used and logistic aspects of such modifications. A detailed structural analysis of materials used in the production of input vectors is, in principle, impossible at this stage in the research. Nevertheless, tracking changes in the range of materials used in production over the years and their potential impact on logistics (e.g. the relation between the type of material and the weight of the finished good) may be an interesting element for research.

Another element describing product parameters in the group of attributes is the size of the product. **Dimension** may be given in terms of cubic capacity, in terms of the maximum length, width, and height of the product or the radius in the case of round products, which will anyway be reduced to a particular volume (cubic capacity) for purposes of transportation and warehousing processes. As has already been stated, dimensions will determine the sales and logistic unit and, consequently, it would be practical to examine the relation between the maximum dimensions of the final product and the dimensions of its packaging. Dimensions of the final product as well as of its packaging are therefore an important item of data and would be necessary to obtain for the study.

The last of the analyzed attributes is the weight of the product (or the weight of the product together with its packaging). The weight of the product basically makes it possible to determine the number of sales units that may form logistic units. Identifying and acquiring data on product weight, in the same way as its dimensions, represent an important element in the model of logistic efficiency of the product. Note, however, that from the point of view of customers, especially those who rely on specialized economic operators for the logistics of product purchase, this data may not always be relevant and therefore it may be reasonably expected that this information will not necessarily be released on the market.

The second of the considered parameters are product properties (Table 9). The elements associated with product properties are vulnerability to transportation and warehousing, and packaging amenability.

Vulnerability to transportation and warehousing would require that at least a few key points be investigated, i.e.:

- the materials from which the final product is made (i.e. accurate data on the materials from which the product is made) with regard to vulnerability to transportation and warehousing;
- the arrangement of the constituent elements or the whole final product for transportation and warehousing, unless they require additional protection or a special arrangement of the constituent elements or the whole product in the packaging – the process of packaging;
- identification of transportation and warehousing infrastructure along with the analysis of the entire logistic chain;
- identification of auxiliary elements of infrastructure used in transportation and warehousing processes, such as pallets, containers, etc.;
- transportation and warehousing infrastructure used, etc.

Potentially, acquiring this type of information might be possible as long as there is access to production plants and to the cooperating companies in the logistic chain. The research would then make an important contribution to the question of logistic efficiency of the product, yet it would require a great deal of effort to carry it out. The research that could be done in this area could be based on scientific observation, i.e. on careful and deliberate observation of transportation and warehousing arrangements supporting logistics in the studied companies. That, however, would require an estimation of research potential.

Packaging amenability, on the other hand, can be considered in one of the variants based on the parameter of attributes – dimensions of the packaging. The point is to get information about the dimensions (volume) of the assembled final product relative to the cubic capacity of the packaging. As a result, it would be possible to use the packaging compression ratio and to approximate certain relationships that emerge from its analysis. It could be assumed that a high packaging compression ratio (above 100%) could imply the need to add packaging to the sales unit, which would entail low packaging amenability. In contrast, a low compression ratio would indicate higher packaging amenability of the final product. However, in order to calculate the ratio, one needs to specify the following parameters of the maximum dimensions of the final product and the maximum dimensions of the packaging of the final product, which may have a high potential for data acquisition. As a rule, in the case of manufactured goods, companies provide mainly this kind of information.

Other investigations related to the arrangement of the elements in the packaging would require thorough data in the form of drawings or photographs, as well as quantitative data about the packaging. That would involve either obtaining data from the company (if the company holds such data) or case-by-case analysis entailing manual opening of the packaging and taking photographs to collect the data.

A further difficulty arises from the very fact of having the information on the composition of the packaging materials provided by the company. Regardless of whether the packaging material is cardboard or wood, additional multidisciplinary research is needed to determine, for example for cardboard, its internal structure, strength, durability, and reusability, which can be very important from the standpoint of the circular economy and its objectives. Consequently, this point breaks open a vast area of research that is very interesting but, on account of the need for multidisciplinary expertise and the necessity to obtain a wealth of data, is difficult to pursue.

The last of the analyzed product parameters is associated with the architecture of the final product – Table 9. The degree of standardization/modularity (reducing the number of parts used), multifunctionality of parts, as well as limited configurability should also be subject to certain types of measurements as part of the research.

Examination of the **degree of standardization** requires access to BOMs (Bills of Material), which, as it is not difficult to imagine, can be a formidable task. Certainly, one may request a company to provide the data, but most likely, such a request would be denied as soon as the company realized that research results were going to be published and disseminated. Standardization is tightly linked to modularity as its indispensable element and can be explored in a variety of ways as long as there is access to data. To get it, one would need to refer to operation and assembly manuals, etc., which would essentially mean diligent extraction and processing of information available online. Aggregation of the collected data would be very labor intensive and time consuming, but doable. The only question would then be the extent to which standardization could be assessed, i.e. whether all elements in a particular product could be evaluated in terms of standardization, e.g. in the case of an item of furniture, the parts to be assembled but also each individual wooden element of the item of furniture.

Multifunctionality of parts further expands the scope of research on the previously stated issue because, in addition to the bill of materials, one would have to get access to the matrix showing where a part is used for different functions in finished products. Whereas in the case of standardization, a matrix summarizing the list of standard elements may be based on operation manuals and assembly instructions, in the case of multifunctionality one would want to get to a specific list of parts used in that way. Without this kind of a list, all products offered by the company (which may involve different scale of effort depending on the company), or deliberately selected products or product groups (selection of a sample that would make it possible to find identical parts put to different uses could be problematic). Data collection potential – average.

Limiting configurability appears to be even more difficult to explore. After all, it requires that it is clarified what kind of customization is dealt with and what its impact on logistic processes is. It would also involve tracking and pinpointing in the system of logistic phases the spot where decisions to purchase affect the supply chain operations undertaken by the company. The analysis should be concluded with clear guidelines and recommendations supporting the work of designers within the framework of logistic efficiency of the product. Potential for obtaining information – rather low.

The delineated scope of research activities associated with the parameters of the product has helped to illustrate the complexity of the necessary research process. The uncertainties that have been highlighted also draw attention to the need to carry the research out in a scaled-down manner. Nevertheless, it appears that undertaking it may be an important beginning to fully describe the concept of Design for Logistics and logistic efficiency of the product.

3.3. Logistic efficiency of the product in the light of the completed research

The discussed prerequisites (the previous subchapter) for conducting research on logistic efficiency of the product provided the opportunity to propose a number of research assumptions.

The first research assumption relates to the selection of research subjects. The Swedish furniture and home accessories maker IKEA contributed to the germination of the idea to take up this topic. It was from that company that the authors proceeded with their unstructured research work, based mainly on observation of the processes of purchase, assembly, and use of IKEA products, which allowed them to focus attention on certain aspects of Design for Logistics, and therefore it seemed reasonable that products supplied by that company should be designated the main (reference) subject of the authors' study.

Consequently, the company in question, construed as a benchmark (point of reference), was selected, based on arbitrary (non-probabilistic) sampling, as one of the subjects in the scientific investigation of the determinants of logistic efficiency of the product. Having thus defined the reference subject allowed us to identify a further group of research subjects. The decision was made to select Polish companies operating in a similar industry and supplying a comparable product assortment group. The approach provides for comparisons pertaining to the issue of logistic efficiency of the product, which makes for a good starting point for the scientific analysis of the topic.

The second research assumption concerns the object of the research. It is worth drawing attention to the fact that the range of products offered by the reference company is very wide, from dishes, decoration accessories, furniture, bathroom accessories, kitchen utensils, mattresses, window treatments, etc., to household appliances. Since furniture as such has a fairly high degree of logistic design amenability[217], it can be expected to be precisely the kind of goods where the company under investigation may look for solutions from the conceptual – improvement model of logistics. That provides an opportunity to apply the principles of Design for Logistics. Consequently, it was decided that this group of products – furniture – will be investigated and subsequently analyzed in the studied reference subject.

The third research assumption involves the availability of data on the objects of the study. As regards the purposively sampled subjects of the research, an important element determining the selection of a particular subject is the possibility to obtain easy access to information about products from that particular company. That could limit in some way the number of subjects, however, on the other hand, it would hardly be possible to search for factors affecting logistic efficiency of the product in companies where there access to specific information would not be possible. Furthermore, from the viewpoint of this study, the opportunity to collect historical data would be very useful in order to be able to assess the extent of product modifications over a certain period of time, e.g. 4 years, affecting its logistic efficiency[218]. Increasingly, the Internet represents an important resource, so the feasibility of exploiting the Internet as a possible source of information was considered.

[217] They provide a great deal of leeway to design the shape/material; choose the dimensions; determine the weight; the necessity to factor in vulnerability to transportation; the necessity to factor in vulnerability to warehousing; the necessity to design packaging adapted to the product; the extent to which standardization/modularity can be exploited; the extent to which multifunctionality of parts can be exploited; the extent to which configurability can be reduced.

[218] Turning attention to logistic efficiency of the product was dictated by the purchase of two identical goods at a particular interval of time.

The fourth research assumption requires that the products examined in view of logistic efficiency be offered on the market for a considerable length of time. This, to some extent, follows from the final conclusions of the second research assumption, however, it also determines the selection of certain companies. The rationale is that in order to be able to identify the company's design efforts to promote DfL logistics, it would be important to compare the changes that have occurred in the products over the years. The authors decided that for domestic companies the year of their establishment prior to 1995 was sufficient. The reason is that the first years of the economic transformation put Polish businesses to the test of their ability to compete in the free market.

The proposed research assumptions resulted in the formulation of the following two principal research objectives:

- **identification of the factors determining logistic efficiency of the product** based on the purposively sampled reference company;
- **comparative analysis of the factors determining logistic efficiency of the product among several manufacturers in the same industry.**

In this study, the authors decided to present selected research results for the reference company, because the reason for undertaking research on logistic efficiency of the product was provided by the changes in the same products of the reference company throughout the years. One of the first goals of the research, which should naturally arise from the completed observation, was to access the data (including assembly instructions) concerning those products of the reference company that could have had their parameters modified. That helped to formulate **the research objective - to compare changes in the parameters of two identical products of the reference company sold at a minimum interval of 4 years**.

Pursuing that research objective meant retrieving the data of the reference company and the assembly instructions, neither of which were provided on the web pages of the reference company any longer. In all probability, such is the policy of the company. Each publicly available and current user manual is accompanied by information that only the most recent version of the manual is available for download, which may suggest that there may be differences between the version offered on the website and the version that came printed with the product.

As was previously stated, during the analysis of the research potential of the reference company, it was found that a lot of information about the products was available beyond the user manual. It was thus critical to gain access to old (now unavailable) websites which could provide a range of information on elements such as dimensions, packaging, materials, etc. The instructions dealt mostly with elements of product architecture, which meant that apart from finding the pdf files of the instructions, which is a little easier, it was necessary to reach the historical web pages, which turned out to be somewhat more difficult to accomplish.

A survey of the available IT tools that could be useful for this purpose helped to discover a web portal collecting this type of data: www.web.archive.org (WayBackMachine), which is a peculiar database of a variety of archived Internet sites. According to the information contained therein, the service includes 336 billion archived web pages. Note, however, that in order to find a product, you could not enter the reference company's website or the name of the product. The search engine operating on this portal is only able to provide information on the same web page code as that of the current page. Accordingly, if the current website of the reference company with the specific product concerned was structured as follows: https://www.ikea.com/pl/pl/catalog/products/50284204/, where the last 8 digits corresponded to the product code, in order to find a match for this product, it had to be assumed that previous versions of the product had indeed been offered. That involved collecting electronic versions of all available catalogues and their painstaking study. Occasionally, the information on a given product was indeed found but the original website actually contained significantly limited content compared to the current one.

Once it was established based on the catalogues that the product had been available for a minimum of 4 years, the URL (Uniform Resource Locator) was copied and pasted in the WayBackMachine search engine, which would then generate information about the pages available in the resources of the site.

The idea of logistic efficiency of the product germinated because of a sofa. For that reason, it was decided first to carry out the search for information about the sofa labelled Sofa 1. That proved to be no mean feat for a simple reason. Every few years, Sofa 1 comes with a cover in a different color and from different fabric. Hence, currently available colors do not represent all the colors that were offered a few years ago. Although the first search for the product yields the address: https://www.ikea.com/pl/pl/catalog/products/S49129209/, once entered into the online archive database, the product with that particular cover would not appear until 2016, which meant failure to meet the research assumptions made concerning a minimum of 4 years of the product availability on the market.

A change of the color entailed the following change in the URL https://www.ikea.com/pl/pl/catalog/products/S49129209/#/S79129203, leaving the original product as the base (marked in grey) and searching the database by the product searched for, marked in yellow. Therefore, in order to find the product marked in yellow, it was necessary to pare the URL down to https://www.ikea.com/pl/pl/catalog/products/S79129203/ and include it in the search through the Internet archives. In that case, again, it turned out that that type of the cover had been introduced onto the market in 2016, which meant the product failed to comply with the research assumptions.

The perusal of catalogues revealed that there were colors that had recurred practically every year and that that had been red and white. Accordingly, S1 sofas in red were analyzed. The product code for the red sofa was https://www.ikea.com/pl/pl/catalog/products/S59133526/, which, after copying and pasting it into the search engine of the Web archive, still indicated 2016 as the year when that cover design was launched on the market. That raised the question: why did sofa 1 in red, which had been available virtually since 2008 (the year of the first online catalogue), show up in the search results of the archive as available since 2016. Following a further review of the pages and catalogues, it emerged that the fabric of the cover had been modified, and consequently also the name of the cover, which also resulted in a change in the code.

Given that a study involving just one product could only serve as a pilot study demonstrating trends in product developments in the reference company, it was decided to expand the scope of the research on the products of that company.

The structure of the study was systematized and organized into the following steps:

1) **constructing a data collection tool;**
2) **purposive sampling of a particular group of furniture and formulating research assumptions;**
3) **temporal vetting of furniture (identification of the year of the market launch of a particular item of furniture);**
4) **analysis of the key parameters of goods (furniture) with regard to their logistic efficiency for those products that fulfilled the research assumptions.**

The data collection tool should not only provide a mapping of the product parameters from the logistic efficiency model, but also enable further analysis of the data. Moreover, since it will rely on the analysis of electronic documents and Web pages, it should be sufficiently robust to allow the data to be collected in one single location. A table was proposed to that end – Table 13.

Clearly identifiable areas are provided in the table which correspond to the following product parameters:

C1 – material used to make the final product;

C2 – dimensions of the final product;

C3 – weight of the final product;

W3 – packaging data – dimensions and weight;

A1 – standardization of components;

A2 – multifunctionality of parts;

A3 – configurability (number of variants and method of personalization).

Table 13 does not include additional elements related to transportation and warehousing amenability. The reason for that is that the data sources preclude completing these two parameters related to product attributes.

At the same time, it should be noted that the categories of data concerning the materials used in the production of furniture should be relevant to the specific character of the item of furniture (in the case of sofas, these are: the cover, frame, backrest, and legs).

Aggregation Table 13 used for the collection of product data merits a short explanation. It was designed to allow the data set included in it to be analyzed in the shortest time while still reflecting product parameters.

Rows and columns have been assigned upper and lower case characters, Arabic and Roman numerals, and combinations of upper case characters and Arabic numerals. The Arabic numerals and the dark blue color correspond in Table 13 to the product offered on the market for a minimum of three years prior to the study. Likewise, the Roman numerals and the light blue color correspond to the product currently on the market.

Table 13. Table for collection of data on product parameters across the years

Product name						A
		Numer of variants:			Price	B
Materials					URL date	C
Main parts materials and raw materials	Name of main parts	Package 1	Packaging data	Package 2		1CW
	…		L		Packaging parameters cm or kg	2CW
			W			3CW
	…		H			4CW
			Weight			5CW
	…	Total weight				6CW
			L	Product dimensions cm		7CW
	Others		W			8CW
			H			9CW
Number of pieces	Assembly piece ID	Assembly pieces				1A
				Date of instructions		2A
				Instructions ID		3A
						4A
			Multifunctionality			5A
						6A
						7A
						8A
						9A
						10A
						11A
			Personalization			12A
						13A
						14A
						15A
						16A
						17A
						18A
URL						D

*Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politech*niki *Łódzkiej, Łódź, 2019, p. 172.*

The individual rows marked with capital letters A; B; C; D represent general data about the product and may include, e.g.:

- product name written with Polish characters;
- product identification number consisting of two strings of 8 digits each separated with a slash (script used for identifying products in the reference company, less dot separators);
- price of the product (old and new);
- number of product variants understood as the number of different variants of the same product (choice of color, fabric texture, etc. – variant does not mean a product series, and thus, it does not mean the choice between a two-seat sofa, three-seat sofa, one-seat sofa, sleeper sofa, etc.);
- "URL date" defined as the date the data was retrieved from the Web page.

The combination of an Arabic numeral and the capital letters CW signifies that the row presents data useful for product parameters associated with both attributes as well as properties. In Table 13, row:

- 1CW provides the number of packages and the materials and raw materials used to make a particular piece of furniture;
- 2CW provides the length of each package and the materials and raw materials used to make a particular piece of furniture;
- 3CW provides the width of each package and the materials and raw materials used to make a particular piece of furniture;
- 4CW provides the height of each package and the materials and raw materials used to make a particular piece of furniture;
- 5CW provides the weight of each package and the materials and raw materials used to make a particular piece of furniture;
- 6CW provides the total weight of all packages and the materials and raw materials used to make a particular piece of furniture;
- 7CW provides the length of each item of furniture as a finished good and the materials and raw materials used to make the particular item of furniture;
- 8CW provides the width of each item of furniture as a finished good and the materials and raw materials used to make the particular item of furniture;
- 9CW provides the height of each item of furniture as a finished good and the materials and raw materials used to make the particular item of furniture.

Note that the data available on the Web pages was often inaccurate as regards the definition of the length, width, depth, and height. Therefore, it was assumed that length would always mean the longest of the specified dimensions, and height always the smallest of the specified dimensions. The decision was taken because the analysis of the process of data collection revealed that over 90% of the dimensions tended to go that way, while the remaining 10% were simply incorrect.

The last element included in the table primarily referred to the parameters of product architecture. The rows marked with an uppercase letter A and an Arabic numeral gave the following data:

- the version of the instructions from which the data was collected;
- the date the instructions from which the data was collected had first taken effect (if no date was given, the date of January 1st of the year which appeared on the last page of the

instructions as part of the wording 'Inter Ikea System BV 2009' was given, in which case the date of the instructions recorded in the table was as follows 01.01.2009;

- component identification numbers denoted with a six-digit code containing Arabic numerals;
- assembly implement identification numbers, consisting of a six-digit code containing Arabic numerals (since there is a closed set of those), all of the assembly implements included in the analyzed instructions appear in Table 13;
- analysis of the instructions in view of multifunctionality, i.e. keeping track of whether a particular component was used in any other context then the previously observed one;
- notes on personalization, i.e. identified aspects of product customization.

Once the described data collection tool had been developed, we could proceed to the second step in the research – the purposive sampling procedure.

Given that a sofa prompted the scientific exploration of this topic, it was decided that the scope of the study should be extended to include a larger number of sofas. However, in order to ensure a better understanding of the topic, another decision was made to also analyze the furniture positioned on the website of the reference company in the next two positions to choose from. It turned out that when the reference company's website was visited, under the **products** tab, the **Spring Summer 2018** collection tab (which was disregarded for obvious reasons) came first, whereas in the next three main locations the following assortment groups appeared[219]:

- sofas and armchairs;
- shelving and storage;
- tables, chairs, and benches.

From the first assortment of **sofas and armchairs two-seat sofas with armrests were selected**. So defined, the research assumptions made it possible to select a group of **11 products which satisfied the established criterion.**

A similar analysis was carried out for the assortment of shelving and storage. **Chests of drawers with three pull-out drawers** were chosen. So defined, the research assumptions made it possible to select a group of **12 products which satisfied the established criterion**.

The last assortment group was tables, chairs, and benches. **Dining tables with a rectangular table top, four legs, and a minimum table top length of 100 cm** were selected. That group included **19 representatives**.

The research objects, selected based on non-probability sampling, had yet to undergo temporal vetting. Temporal vetting was the process of identifying the length of time the

[219] https://www.ikea.com/pl/pl/# retrieved 09.08.2018.

products had been on the market. It was assumed that the research would involve products whose presence on the market exceeded 3 years, i.e. there was data available on these products (archived Web pages or electronic documents providing all the information to complete the table) dated 2015 and earlier.

A certain inconvenience that accompanied the temporal vetting was the change of product codes due to the changes in the color of the furniture, its covers, and its upholstery. That being the case, the IKEA catalogues for the relevant years had to be reviewed in order to find the codes of the products in different colors or the names of, for example, the covers.

As a result of that type of verification, the sample was found to have decreased significantly, which is shown in Table 14.

Table 14. Final group of research objects, IKEA

Sofas		**Chests of drawers**		**Dining tables**	
Name	**Year of available data**	**Name**	**Year of available data**	**Name**	**Year of available data**
KIVIK	2012	MALM	2011	BJURSTA	2014
EKTORP	2012	BRIMNES	2012	LERHAMN	2014
KNOPPARD	2017	HEMNES	2012	TARENDO	2013
DELAKTIG	2017	ASKVOLL	2017	MELLTORP	2014
KLIPPAN	2011	LOTE	2016	EKEDALEN	2018
VIMLE	2017	VIGRESTAD	2014	VANGSTA	2017
NORSBORG	2016	SONGESAND	2017	INGO	2011
YPPERLING	2017	RAST	2011	STORNAS	2012
TIDAFORS	2011	TARVA	2012	NORRAKER	2015
GRONLD	2018	KOPPANG	2017	INGATORP	2012
LANDSKRONA	2017	NORDLI	2017	IKEA PS 2012	2012
KARLSTADT	2011			TORSBY	2011
				LISABO	2015
				VASTANBY	2015
				DAGLYSA	2018
				NORDMYRA	2018
				GLIVARP	2017
				OVRARYD	2017
				YPPERLING	2018
				INDUSTRIEL	2018
				TINGBY	2017

(grey) – Furniture not meeting the criteria for the selection of research objects
(green) – Furniture meeting the criteria for the selection of research objects

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 178.

Since the results of the research for all groups of the furniture were presented in "*Logistyczna sprawność produktu – projektowanie wspomagające logistykę*"[220] in this part of the work, the results concerning generational changes in the sofas will be reported.

For research purposes assumptions were made that it would be necessary to collect information from the Internet sites on the following elementary elements:

1) the arm of the sofa;
2) the cover of the sofa;
3) sofa legs;
4) and the backrest (as long as it was not integrated with the frame, e.g. cushions).

This is important because the structural design of a piece of furniture will naturally affect the shape of the table for the aggregation of data. Moreover, analysis of product parameters in terms of materials used to make particular elements corresponds to the first attribute among the product parameters in the model of logistic efficiency of the product.

As regards the first parameter (C1 – shape/material), the investigation revealed that the materials used for the cover of the finished good had undergone the greatest change since cotton was replaced with a blend of natural cotton and synthetic polyester.

As far as the construction materials of the sofa are concerned, they have generally remained unmodified. There are differences in terms of more or less precise specification of the materials (e.g. solid wood / solid pine), but the materials themselves are basically the same. The second parameter C2 (product dimensions) has not been changed for 6 years. Nor has parameter A1 (standardization) with respect to components.

Note that the instructions for the old product are not dated (2009 was adopted as the only date featured in the instructions) whereas the latest edition of the instructions for the new product is from 2016. That means that the company pursues a policy of minimum alterations to both product design and user manuals / assembly instructions. Minor modifications have been made to the product packaging, i.e. parameter W3. An increase in the weight of the sofa packaging (packaging O1) and a minor enlargement of its dimensions (max. 3 cm per dimension) are observed. A major change has occurred in the case of parameter A3 (personalization), where the number of optional covers has dropped by nearly 40% (from 14 to 9). It has not been established that any other part was used in this product for another application under parameter A2.

[220] Bielecki M, Logistyczna sprawność produktu – projektowanie wspomagające logistykę …, op. cit., pp. 179-199.

Worth noting is the fact that the product price and ID have changed, which merits explaining. IKEA changed the names of its covers in 2015 (due to a change in the materials used for the covers). Therefore, even though the color of the covers for the two examined sofas was identical (white), it was not possible to get to the pre-2015 sofas based on the 8-digit product ID because the change in the cover generated a new product ID. Therefore, the names of the covers were retrieved from the pre-2015 catalogues and a sofa with a cover in the same color was selected as the object of the study (although product suggests that it is a different product).

However, in order to be able to present a synthesis of the results obtained for all sofas, the decision was made to design a tool which would show changes, and their trends, in products throughout the years. The tool operated on the principle of comparing each of the quantitative parameters (length, width, weight, etc.) to demonstrate the tendencies of the changes (e.g. the relation: a modified dimension less the original dimension). If the trend was positive (length, weight, number of packages, variants, etc. increased), the respective direction of change assigned to them was up, which was symbolized by an arrow pointing upwards against a dark blue background – "↑". On the other hand, the reverse trend was symbolized by an arrow pointing downwards against a light blue background – "↓". Materials used in production were subject to quality assessment and also found their rightful place in the tool. Table 15 provides a visual presentation of the obtained research results illustrating the quantitative and qualitative trends in generational changes in product parameters in the investigated group of sofas.

Table 15 shows that neither the dimensions nor the number of packages changed for a majority of the sofas. There were changes in the positive direction in the dimensions of the packages (in new products they are larger than in the old ones), while for two products the parameter of standardization changed, which means a change in the number of parts – in the first case, the number of the parts increased, in the second case it decreased, and in three instances it remained the same. With one product (the Klippan sofa), different components were used. The number of sofa variants, associated with personalization, had a tendency to decline, which means that the company limited the range of furniture choices (for sofas, mainly the range of the covers). The price of the analyzed goods fluctuated – each time it either increased or decreased. Interestingly, the assembly instructions for Klippan sofas have not been changed for 12 years, which means that the company has not modified the design of the product.

A qualitative analysis of the materials reveals only a few changes. Noticeable is a diminishing level of detail in the descriptions of the materials used, e.g. (instead of solid pine, there is solid wood). The direction of these changes is such that the number of details is declining with newer products. The only exception is the Klippan sofa, in which materials were changed from solid wood to plywood, particleboard, and fiberboard, the ultimate consequence of which was primarily a change in the price of the product, advantageous to the customer, and in the logistic parameters of the packaging associated mainly with weight.

Table 15. Aggregated research results for the parameters of IKEA products in the sofa category over a period of 3 years

Product parameters	**EKTORP**	**KIVIK**	**KLIPPAN**	**KARLSTAD**	**TIDAFORS**
C2.1. Length [cm]		↑			
C2.2. Width [cm]				↓	
C2.3. Height [cm]					
W3.1. Number of packages	2	3	2	2	2
W3.2. Package length [cm]	↑ ↑	↑ ↑	↑ ↑		↓ ↓
W3.3. Package width [cm]	↑ ↑	↑ ↑	↑ ↑		↓ ↓
W3.4. Package height [cm]	↑ ↑	↑ ↑	↓ ↓		
W3.5. Product+packaging weight [kg]	↑ ↑	↓ ↓	↓ ↓		↑ ↑
W3.6. Total weight [kg]	↑	↓	↓		↑
A1. Standardization			X	X	
A1.1. Change in the number of assembly pieces			↓	↑	
A3.1. Number of variants	X	X	X	X	X
A3.2. Change in variants	↓	↓	↑	↓	↓
Price	↑	↓	↓	↑	↑
Lapse of years between the relevant instructions	X				X
Lapse of years between 2018 and the latest instructions	2	9	15	9	7
Lapse of years between the analyzed products based on URL	6	6	7	4	7
C1. Materials – qualitative analysis	No change – minor changes in materials	Change in cover/uphostery materials. Other materials unchanged. Minor changes in materials	Change in cover/uphostery materials. Other materials unchanged. Minor changes in materials	No springs in the new model. Change in the description of materials	Change in cover/upholstery materials. Minimization of materials used for the frame and backrest. Minor changes in materials
A1.2. Standardization – qualitative analysis			Different assembly pieces used		

Directions of changes in product parameters – parameter value: increased – ↑; decreased – ↓; constant ×

Source: compiled by the authors based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 181.

Further research made it possible to establish the degree of packaging compression as an analytical indicator of product parameters in the area of properties (W3) in the model of logistic efficiency of the product. The research objective related to packaging compression was formulated as follows: **identification of the degree of packaging compression for the investigated product lines and for all examined subjects (sofas, chests, and tables).**

To achieve this goal, the following data was required – product parameters (C2 dimensions) and packaging parameters (W3 dimensions). The data collected for the tables aggregating data on products were compiled into new tables where the compression ratios were calculated.

As the results of the research completed in this area show the average packaging compression ratio for the target group of IKEA research objects (Table 14) is at the level of 33% (Figures 14-16).

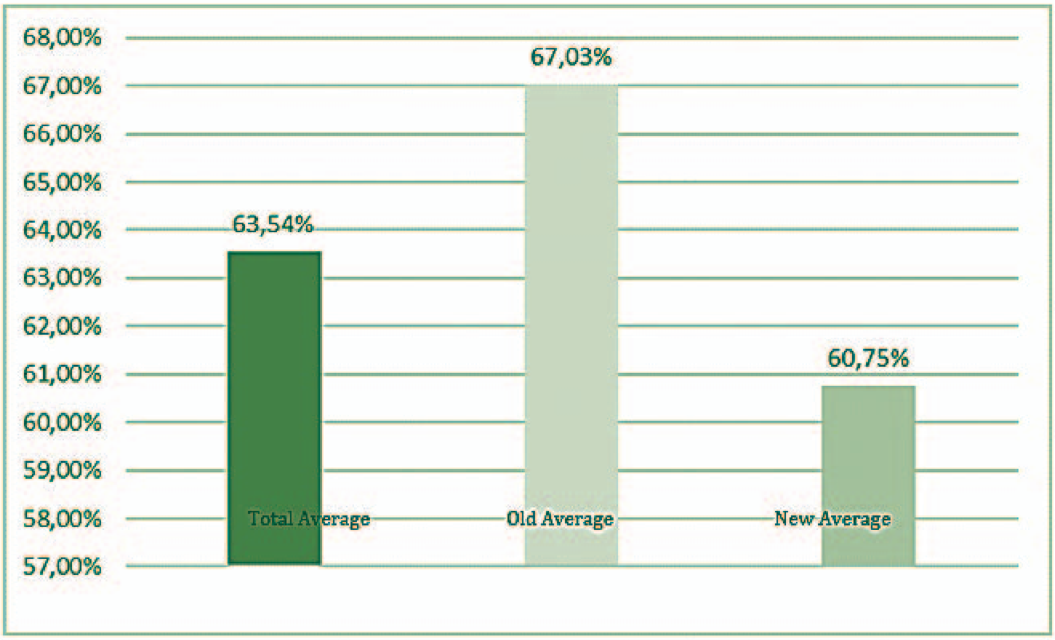

Figure 14. Packaging compression ratios for the analyzed IKEA sofas

Source: compiled based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 197.

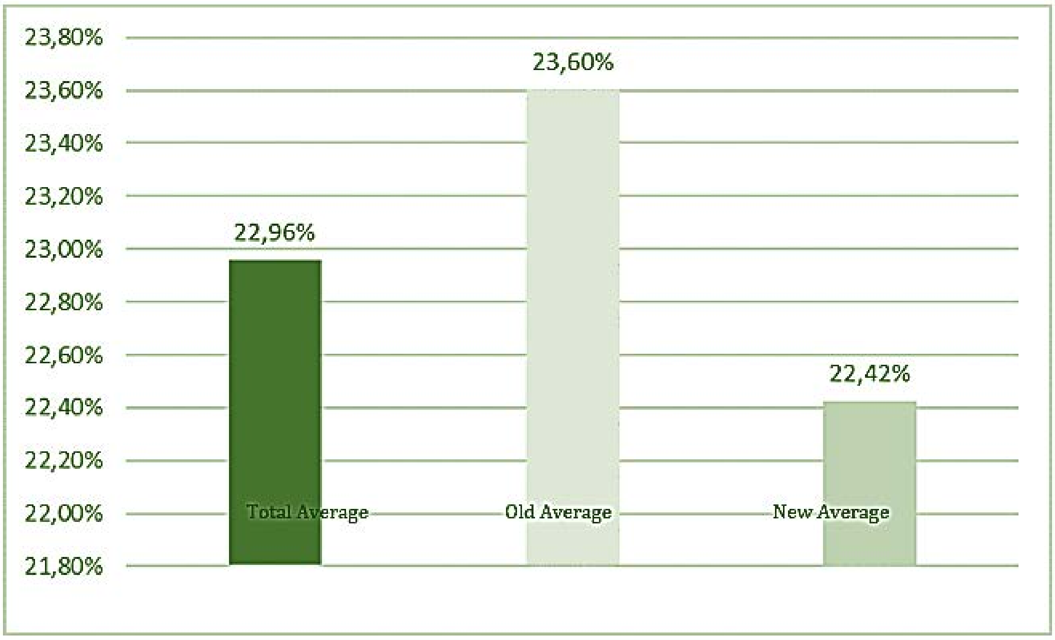

Figure 15. Packaging compression ratios for the analyzed IKEA chests of drawers
Source: compiled based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 197.

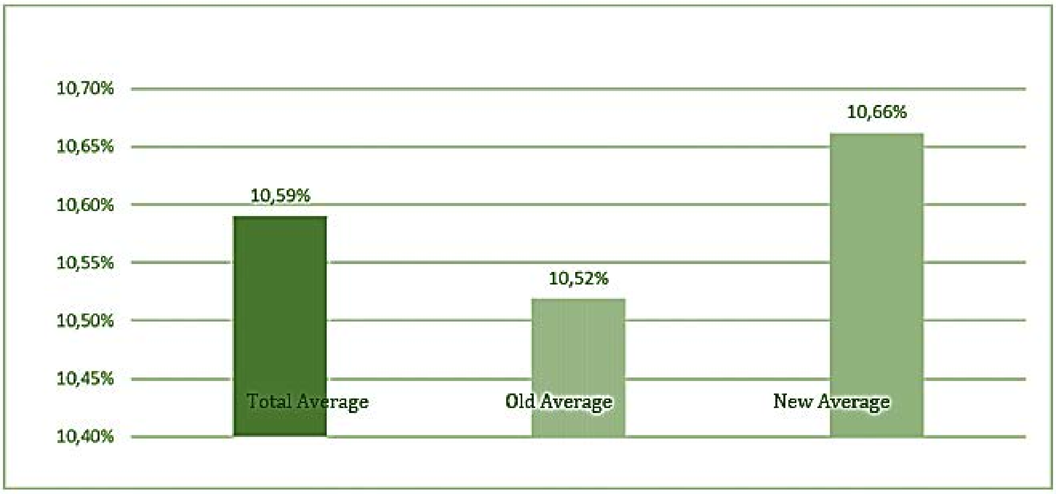

Figure 16. Packaging compression ratios for the analyzed IKEA dining tables
Source: compiled based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 199.

Setting these results against the sofas and chests, one can clearly see that the tables, which is also attributable to their construction, have the lowest average packaging compression ratio. Relating it to the sofas, it is six times lower, whereas taking the chests of drawers as the reference point, it is only just over twice as low.

What is important, however, is that the analysis of the results provided insight into another important research context concerning the degree of standardization of components in the examined products. It implied the definition of the next research objective, which was specified as follows: **to identify the degree of standardization of component parts in the investigated product groups and in all of the studied objects**. That research objective could be accomplished in at least the following three main aspects:

- identification of the degree of standardization in the old furniture that had been on the market for more than 3 years, which were examined during the first stage of the research;
- identification of the degree of standardization in the furniture currently available on the market, which were examined during the first stage of the research;
- identification of the degree of standardization in a larger group of furniture currently available on the market which were not examined during the first stage of the research.

Establishing the degree of standardization for the furniture that had been analyzed generationally in terms of logistic efficiency of the product called for additional tables which would show what types of components were used in the analyzed groups of sofas, chests, and tables. Since it was highly likely that specific components would recur in certain furniture assortments, which was associated with the assumption that the degree of standardization of the component parts in the reference company is relatively high, a data analysis process had to be designed and appropriately structured. The stages in the process of analyzing research results in the context of determining the degree of standardization in the examined products were broken down into the following steps:

- elimination of duplicate part identification numbers within each assortment group;
- constructing a graphic matrix to illustrate the degree of product saturation with component parts for each assortment group;
- eliminating duplicate part identification numbers within all assortment groups;
- building a graphic matrix to illustrate the degree of product saturation with component parts for combined assortment groups;
- building a graphic matrix to illustrate the degree of product saturation with component parts for a randomly selected group of products sold on the market in 2017-2018.

The first stage, the removal of duplicate parts, meant that the total number of parts and the number of parts remaining after the elimination of duplicates had to be determined – Figure 17.

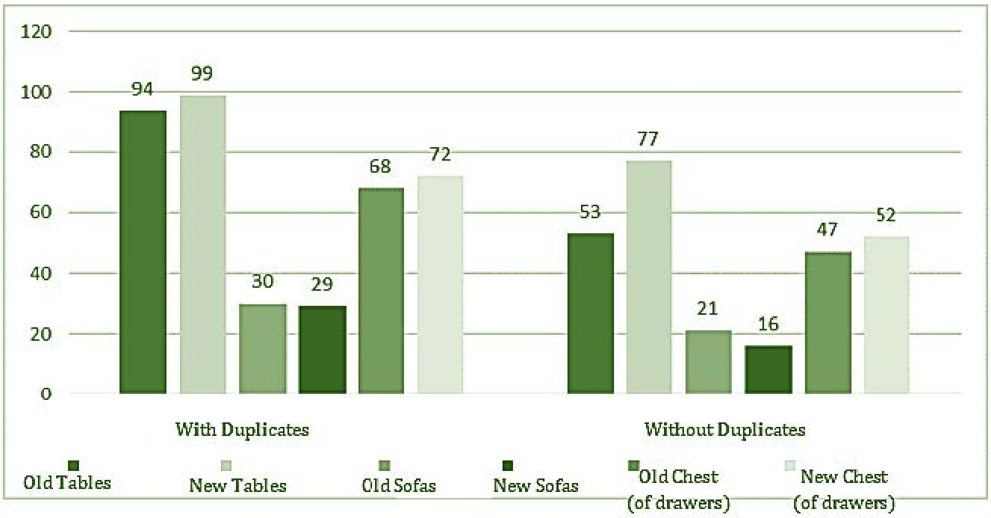

Figure 17. Total number of component parts (with duplicates) per assortment group relative to the total number of parts (without duplicates), IKEA
Source: compiled based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 188.

Figure 17 reveals that the dining tables had the largest total number of component parts, even once the duplicates had been removed. The number of parts eliminated due to their reappearance in the assembly instructions can be an important indicator of the degree of standardization. However, the indicator is vague to some extent because it fails to show the overall scale of the phenomenon (a part can be duplicated one or more times, which is not reflected in the proposed quantitative relation).

Therefore, it was undertaken to calculate the rate of duplicates - the rate of duplicates is presented in Figure 18.

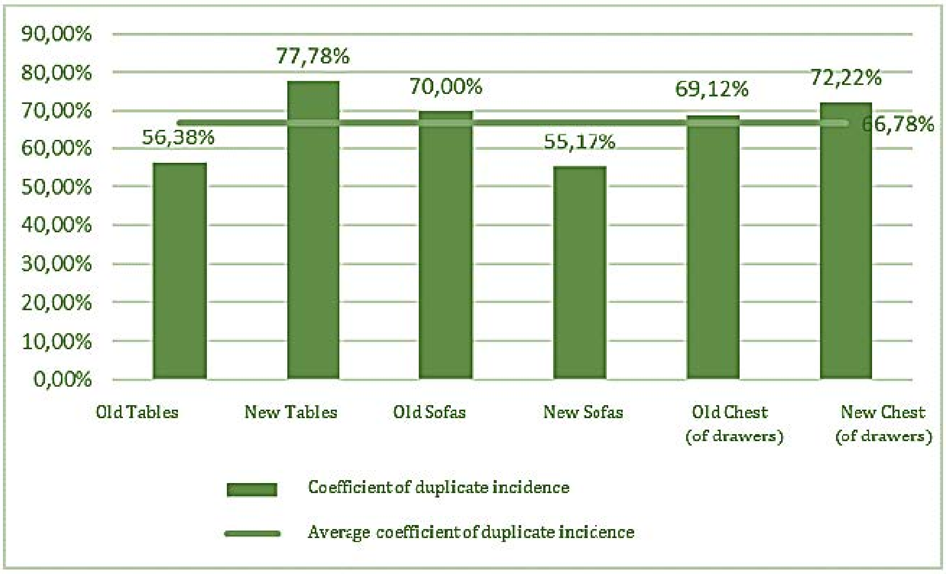

Figure 18. Percentage share of parts after the elimination of duplicate elements, IKEA
Source: compiled based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 188.

As the presented Figure 18 makes evident, the largest number of duplicate part elimination occurs with the old dining tables and new sofas. Consequently, it can be assumed that for those cases, the degree of part repeatability will be greater than for the parts with a lower indicator. Unfortunately, as mentioned earlier, that indicator does not allow to specify the scale of the described phenomenon. For that reason, in order to be able to compare and analyze the two parameters in a qualitative way, a tool named the standardization matrix was constructed, which much better elucidates the results of the research on the discussed problem.

The standardization matrix was developed so as to make the degree of standardization of parts perceptually conspicuous. It is based on a system in which the rows represent individual finished goods, whereas the columns represent the parts used to assemble the final products - Figure 19.

	105016	100469	131337	100843	118054	110912	101350	118331	103430	109060	100325	105163	100712
MELTORP	8												
		4											
			4										
				4									
					8								
BJURSTA						4							
							12						
								4					
									4				
										16			
											24		
												2	
													8
				8									
LERHAMN													
						4							
							2						
													8
				8									

Figure 19. Section of the standardization matrix for the selected dining tables marketed before 2015, IKEA

Source: compiled based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 189.

Figure 19 illustrates the extent to which particular parts are used in particular products. Thus, the part with the identification number 100843 (the fourth column), is featured as a component in all three presented dining tables. The difference lies only in the number of instances this part is used in the presented assortment group. In contrast, the part bearing the identification number 100712 (the last column), appears only in two of the three furniture items shown in the table, an identical number of times.

When similar assortment groups are analyzed, it can be assumed that a particular assortment group should have a fairly high rate of part standardization. The assumption comes from the fact that, for example, the assortment group of the dining tables appears to be so simple in its design that it would be implausible to diversify the component parts so that each table could have a separate assembly system.

To prove the presented assumption, a standardization matrix was compiled for each of the groups separately as well as for all the groups combined.

Based on the analysis conducted with the aid of the matrix, the authors arrived at two important conclusions. First, there is a large group of component parts associated only with a particular type of the table. That is puzzling inasmuch as the assumption was that for objects as structurally simple as that ("a table with a table top and 4 legs") the degree of standardization would be significantly higher. Second, the reference company does not regard the standardization of components as a vital element in the design of its products. The calculated rate of standardization saturation for all three assortment groups under consideration, both in terms of the "old" furniture (sold on the market before 2015) as well as the new furniture marketed in 2018 (Figure 20), clearly indicated that the average level of standardization at the company was 25%. If the standardization saturation rate were to reach 100%, the company would be using all component parts in all of the examined products.

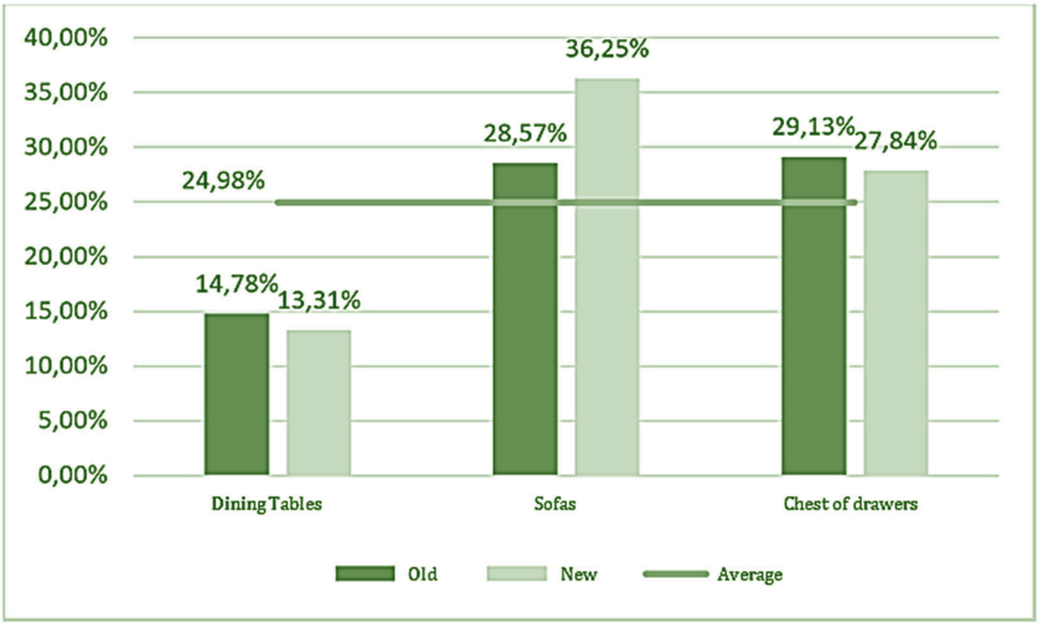

Figure 20. Rate of standardization saturation. Percentage share of parts remaining after the elimination of duplicate elements, IKEA

Source: compiled based on Bielecki M., Logistyczna sprawność produktu – projektowanie wspomagające logistykę, Wydawnictwo Politechniki Łódzkiej, Łódź, 2019, p. 191.

The results of the research done to compare selected generations of the furniture failed to reveal well-defined trends for the studied products. However, it did show certain types of relationships which can be characterized in the following points corresponding to product parameters[221]:

- the materials used in the analyzed furniture have not shown any tendency towards specific changes over the years **(C1 – shape/materials)**;
- dimensions of the finished goods have remained fairly constant over the years **(C2 – dimensions)**;
- packaging compression ratios vary between assortment groups and have not changed in any significant way over the years (a tendency has been observed towards minimization of the cubic capacity of the new packaging compared to the old packaging, rather than the reverse) **– (W3 – packaging)**;
- the degree of standardization of component parts leaves ample room for optimization **– (A1 – standardization)**;
- furniture personalization options show a decreasing trend and involve only the selection of the color of a standard piece of furniture or the selection of a cover for a standard piece of furniture **– (A3 – personalization)**.

The absence of clear trends in design modifications of the products may be attributed to the fact that a majority of the examined products have already been optimized, which would be corroborated by the relatively steady values of the product parameters throughout the researched period.

The study of the reference company could have been expanded to include a number of aspects, e.g.: trends in modular furniture and the extent to which modularity is exploited, or analysis of warehousing and transportation amenability, however, these would require further research and store visits.

The next stage of the research involved a comparative analysis of the selected parameters of the product in the model of logistic efficiency of the product in other companies in a related industry, of which Bielecki[222] provides a detailed description.

The results of his analysis reveal certain tendencies in the activities of the reference company and the companies in related industries to consciously or subconsciously take logistics

[221] The results are presented in more detail [in:] Bielecki M, *Logistyczna sprawność produktu – projektowanie wspomagające logistykę …*, op. cit., 2019.
[222] Bielecki M, *Logistyczna sprawność produktu – projektowanie wspomagające logistykę …*, op. cit., pp. 197-242.

and the supply chain into account in the design of their products, aimed at supporting logistics and the supply chain.

Adopting the model of logistics which involves logistically efficient products as the effect of applying Design for Logistics, it should be pointed out that at the moment, neither the reference company nor the surveyed industry-related companies have solutions in place that would be aimed at "closing" the loop in the circular economy. Consequently, what is lacking is an intentionally designed and organized system which would ensure effective collection and reprocessing of used final products.

However, the effectiveness and efficiency of the logistics of the studied companies can be examined by analyzing parameters of the product according to the model of logistic efficiency of products. From the standpoint of the performed generational research and investigation of the currently marketed final products, a number of particular determinants have indeed been observed in the product parameters of the reference company, which are as follows:

- with respect to the attributes:
  - sticking to a tight and standardized group of raw materials (e.g. wood, polyurethane foam, etc.);
  - considerable variety of dimensions and weights of furniture items within one assortment coupled with a relatively high cubic capacity to weight ratio;
- with respect to the properties:
  - dimensions of the packaging vary in time but to only to an extremely limited extent (relatively small variability);
  - packaging compression ratio relatively constant for particular product groups;
- with respect to the architecture of the product:
  - the rate of standardization saturation at a very high level as regards assortment series and series of modular assortments;
  - few changes in component parts and assembly instructions over time;
  - multifunctional use of parts has not been observed;
  - personalization limited to several colors and expanded by combinations of colors;
  - tendency towards keeping the number of possible variants down to the optimum that the company deems appropriate.

Furthermore, analysis of the research results revealed a number of general trends concerning the parameters of the reference company products that influenced logistic efficiency of IKEA products. These included the following:

- consistent use of structural materials over time;
- for wood and wood-based structural materials, a tendency to maximize the use of wood as a renewable material;
- dimensional and weight stability over time (changes do occur but to a very limited degree);
- relatively high cubic capacity to weight ratio for the analyzed furniture assortments and series (which may point to a close relationship between the increase in weight and the increase in volume being a consequence of a similar approach to the processes of designing assortment groups of goods);
- relative stability over time of the packaging cubic capacity and weight as well as the packaging compression ratio for particular assortment groups and product series;
- relative stability over time of the standardization saturation within the assortments;
- considerably superior standardization performance for product series and modular product series than for particular assortment groups;
- poor standardization performance between assortments;
- multifunctionality of parts – use of a particular part for several different applications – has not been observed for the analyzed sample;
- personalization limited to several variants or combinations of variants.

The research results for the companies in related industries were only summarized in the general area, which led to the identification of the following trends[223]:

- much greater use of laminated particleboard rather than solid wood;
- structural components not standardized in terms of dimensions or materials (in the reference company, that aspect could not be examined);
- no clearly prevalent dimensions in the analyzed assortment groups;
- much weaker cubic capacity and weight correlations;
- individual packaging compression ratios and ratios for selected assortment groups on a level comparable to that of the reference company (IKEA), but only for the furniture items with a relatively simple structural design such as tables;
- due to the availability of data, it was possible to determine the packaging space efficiency rates;

[223] Bielecki M, *Logistyczna sprawność produktu – projektowanie wspomagające logistykę …*, op. cit., pp. 243-247.

- rates of standardization for certain product assortments comparable to those of the reference company;
- as in the reference company, low rates of standardization for component parts between assortment groups;
- failure to ensure multifunctional use of parts;
- on the relatively lowest (advantageous) from the perspective of logistics, level for all furniture assortments compared to the analyzed assortments of the companies in related industries.

The results of the completed research made it possible to identify the prevailing trends in the examined companies, and also to verify certain practical methods that enable the analysis of selected product parameters in terms of logistic efficiency of the product. The following indicators have been verified for this approach:

- the cubic capacity to weight metric relevant to product attributes associated with product dimensions and weight;
- the indicators of packaging compression and of packaging space efficiency relevant to product properties associated with the cubic capacity of the packaging;
- the rate of standardization detection and the rate of standardization saturation relevant to product architecture parameters.

Each of these indicators helps to illustrate selected factors affecting logistic efficiency of the product.

The cubic capacity to weight metric should become instrumental in assessing the stability of design processes. The higher the positive or negative correlation of this indicator, the stronger the dependence between the cubic capacity and weight. When the entire assortment group is measured, a strong correlation (Pearson's correlation coefficient closer to 1 or -1) indicates stability of the cubic capacity to weight representing a linear relationship in which an increase in the cubic capacity of the packaging of a product results in an increase in the product weight. Stability of this indicator (high correlation coefficient) is also a very important element for planning warehousing and transportation processes for assortment groups. However, applying it to the said processes requires further research.

The packaging compression ratio is an assortment indicator, i.e. it helps to analyze the how well a finished good "fits" into the particular packaging. The higher the value of this indicator, the closer the product is to its original dimensions. The lower the value of this indicator, the lower the cubic capacity of the product compared to the final product. That means that, for the purposes of transportation and warehousing processes, the volume of the product has changed either due to a high degree of disassembly or through other operations to compress the final product, e.g. emptying the air (vacuum packing).

The last of the proposed indicators concerning standardization of component parts enables assessment of the degree of product standardization. Duplication indicator, representing the number of duplicated component parts in the final product, explicitly depicts trends concerning homogenization of components. The standardization saturation rate quantifies the degree of standardization in terms of the incidence of individual parts in each product. It requires further refinement with a graphical representation of the standardization saturation and the incidence of parts in all products. Consequently, measurement of the level of standardization both within and between product assortments is enabled.

To summarize, the following conclusions concerning Design for Logistics can be drawn for the investigated group of products:

- use of prevalent construction materials (preferably with a high capacity for recovery from end-of-use/life final goods);
- using standardization of product attributes (materials, dimensions, weight) both across product generations as well as across products currently available on the market to the maximum extent;
- maximizing positive relationships between the cubic capacity and weight of product packaging in the area of properties – aiming for a strong correlation for series, assortments, and product groups;
- minimizing the packaging compression ratio by means of feasible market practices (e.g. disassembly, vacuum packing, etc.) minimizing cubic capacity of the packaging;
- maximizing packaging space efficiency indicators;
- using standardization of parts and components in product series, assortments, and groups to the maximum extent – maximizing the standardization saturation indicators;
- optimizing product personalization and harnessing the possibility of creating various customization combinations with a limited number of variants.

The review of the literature, the observations as well as the case study allowed us to respond to and verify the proposed research methodology complete with metrics and indicators for analysis and evaluation of selected aspects of logistic efficiency of the product. Polydimensional and multidisciplinary analyses enabled the formulation of the model of logistics which incorporates logistic efficiency of the product as well as introduction of the model of logistic efficiency of the product on the level of the product, incorporating the three key product parameters - attributes, properties, and architecture.

CONCLUSION

This study is an important contribution to helping manufacturing companies realize the significance of product design in view of logistics and the supply chain. The extent to which tools for the organization and management of logistics is indeed limited, in which case modification of product attributes, properties, and architecture becomes a major aspect of rationalization and optimization of logistics processes. As shown in the study, optimization of product parameters depends strictly on product design amenability. What seems to be crucial, however, is the need to raise awareness in the manufacturing companies of the possibility of interacting with the product at the design stage in a way which would ensure that the logistics system downstream operates in an optimal mode.

Acting on a product to support logistics and supply chain processes has been known as *Design for Logistics*. The outcome of Design for Logistics is a product which is logistically efficient, and the description of the prerequisites for such a product is provided in the concept of logistic efficiency of the product. The complexity and multidisciplinarity of the subject matter demonstrates that this work is a valid starting point in the scientific discourse on the problem of implementing engineering approaches to products designed for logistics support.

The presentation provided in this study certainly represents an original and innovative treatment of the problem. The approach leads, first of all, to a conceptual structuring of the area of Design for Logistics within the deeper, underlying concept of *Design for eXcellence*, while furthermore introducing the notion of logistic efficiency of the product, which is concisely summarized with the 5Es: *Easy Purchase*; *Easy Production Logistics*; *Easy Distribution; Easy Return of end-of-use products from the market and reuse of products or their parts*; *Easy Consumer Logistics*. The proposed research methodology for logistic efficiency of the product is another valuable contribution as are the tools provided in the form of metrics and indicators, which enable the analysis and evaluation within the presented area of research.

The proposed model of logistics incorporating logistic efficiency of the product, as well as the model of logistic efficiency of the product framed within the system of product parameters has certain limitations on account of the breadth of the described phenomenon. They arise from at least several very important considerations, which include:

- research multidisciplinarity affecting the described phenomenon;
- heterogeneity of the determinants of logistic and supply chain processes;
- variety of products offered on the market;

- the need to accommodate product design amenability;
- the area of data collection.

The first of these limitations clearly points to the need to narrow down and flatten the described phenomenon in many different research aspects. Through such deconstruction, a model of logistics has been formulated which includes logistic efficiency of the product, relies on the circular economy, which, in general terms, appears to be relatively straightforward. On the one hand, the model of logistic efficiency of the product has been downsized to such a degree that it could be verified empirically with the studied research subjects. On the other hand, a number of issues, e.g. quality, ergonomics, production, and marketing (truly relevant from the perspective of the end customer), which are inherently vital in the process of product design, have been excluded. It should be stressed however that the recommendations that have been provided for practical applications, which can facilitate the process of Design for Logistics, in many cases may also prove beneficial for the quality or production processes, for example, standardization of product parameters.

The second constraint involves the need to accommodate in product parameters the particularities of logistic processes (resulting from the functional breakdown of logistics), as well as, to a much higher degree, the elements of the supply chain. Given the level of generality of the model, one should recognize that the variety of arrangements for supply chains and logistic processes alone would preclude the development of a single, coherent model. Just as at the present time it is difficult to pinpoint the best logistic practices (we can speak of trends, directions of development, etc.), so it has been equally challenging to capture the elements of modern logistics in the model, for example automated freight identification systems, customer service, or automation of transportation, warehousing, and packaging processes in each fragment of the supply chain. That is why the model required to be simplified to the maximum possible extent in order to enable more extensive research work in areas that would enrich the model.

The third of the model's limitations concerns confining investigations to relatively homogeneous products not only in terms of the industry but also in terms of design. Indeed, no comparison can be drawn between products whose designs are dissimilar. Therefore, the model may be reserved for product groups of comparable assortment, whereas the results of the analyses may not be generalized and treated as benchmarks.

Finally, it is important to point out that the entire concept of the model of logistic efficiency of the product has been described for products demonstrating high design amenability. Thus, products whose design amenability is relatively low are eliminated in the natural course of events, and thereby are set apart for organizational and management practices whereby the effectiveness and efficiency of logistics processes can be increased.

The last of the points listed is concerned with the acquisition of data in accordance with the presented methodology of research on logistic efficiency of the product. Availability and quality of data come forth as critical factors in the pursuit of research goals. Unavailability of product data on the World Wide Web renders it impossible to undertake research efforts in line with the proposed methodology, thus compelling researchers to acquire data directly from manufacturers.

The scope of the presented study certainly does not exhaust the range of issues related to Design for Logistics the effect of which should be logistically efficient products. The purposive sampling of simple finished products as research objects has enabled putting forward the described model, while leaving the entire spectrum of research projects to be continued or commenced. Since the range of particularized studies for such a general model is virtually infinite constrained only by the limits of the creative imagination of researchers, in principle, full description of research directions is only feasible for level 1 – the model of logistic efficiency of the product. For level 2 – logistic processes, and level 3 – supply chain, only general directions for future research can be suggested. The most important propositions for further scientific study include:

- incorporating determinants of the shape of the final product and its influence on logistic processes into the model of logistic efficiency of the product;
- incorporating transportation and warehousing amenability as a distinct element into the model of logistic efficiency of the product;
- incorporating aspects of product personalization into the model and defining its impact on logistic efficiency of the product;
- investigating relationships between the packaging compression ratio and the complexity of the finished product;
- developing an integrated tool to assess logistic efficiency of the product;
- verifying the enhanced model of logistic efficiency of the product for other product groups to generalize and consolidate the model of logistic efficiency of the product on Level 1;
- including end-of-use final products within the scope of research and delineating outlooks for their use in the design or modification of new products;
- seeking to expand the analytical tool kit for the model with further indicators and metrics of logistic efficiency of the product.

As regards general directions for further research the following should be enumerated:

- transposing the model of logistic efficiency of the product to the level of logistic processes – level 2, and seeking to identify determinants of the functioning of the model, as well as determining relationships between parameters of the product and of logistic processes;
- bringing the model of logistic efficiency of the product to the level of the supply chain – level 3, and proceeding in the same way as for level 2 of the presented model.

The suggested directions for research will certainly have an effect on the proposed research methodology concerning logistic efficiency of the product, which should improve the methods and tools applied in the studies of the discussed subject matter. Broadening the range of research instruments will help open up the possibilities for research based on the presented model.

To conclude, this study is an original work (the review of the literature has not yielded comparable research reports) and, despite the identified limitations, it establishes a set of recommendations for Design for Logistics and presents a methodology of research on logistic efficiency of the product.

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