SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2022
ORGANIZATION AND MANAGEMENT SERIES NO. 186

OVERVIEW AND PRIORITIZATION OF CRITICAL SUCCESS FACTORS IN NPD MODELS FOR THE CHEMICAL INDUSTRY

Iwona ŁAPUŃKA[1*], Joanna BARTON-PUDLIK[2], Dominika JAGODA-SOBALAK[3]

[1] Opole University of Technology; i.lapunka@po.edu.pl, ORCID: 0000-0003-1472-1477
[2] Johnson & Johnson MedTech, Solothurn, Switzerland; asiabrtn@gmail.com
[3] Opole University of Technology; d.jagoda-sobalak@po.edu.pl, ORCID: 0000-0003-3085-6603
* Correspondence author

Purpose: The purpose of the article is to review NPD models and identify critical success factors for new product development in the chemical industry.
Design/methodology/approach: The systematic review of the literature was applied in the paper and the AHP method was used to build a hierarchical model for determining the importance of CFSs.
Findings: The paper characterizes the concepts of new product development and general models of new product development. Older (pre-2000) and newer generation studies were included among the models described. Data analysis of new product development studies in the chemical industry was carried out. Based on the literature analysis, key factors determining the success of a new product were selected, with a division into general and typical elements of the industry in question.
Research limitations/implications: The prioritization of CFSs will allow in the next step the analytic hierarchy process of NPD models, on the basis of which it will be possible to determine which of the analyzed models is most suitable for chemical products.
Practical implications: Most chemical products are designed using trial-and-error techniques based on experimentation, making NPD in the chemical industry more iterative. This often involves generating a huge number of chemical components, and this means that the search area can be very large. It is therefore reasonable to look for decision support tools to facilitate the selection of necessary components. The selection of chemical product ideas should be based not only on an analysis of what is possible to produce, but also on an analysis of what the market would like to buy. The specifics of chemical products and changes related to 21st century trends are forcing the determination of appropriate CFSs for the chemical industry.
Originality/value: The chemical industry is one of the world's key industries, whose products are used in almost every area of life. Despite this high relevance, there has been no attempt to date to systematize the issues of developing new product lines or portfolios in this industry.

Keywords: new product development model (NPD), critical success factors (CFSs), analytic hierarchy process (AHP), prioritization, chemical industry.

Category of the paper: research paper, general review.

1. Introduction

Increasing customer demands related to the quality of services and products offered, and the consequent difficulty of maintaining a good market position, affect the need for businesses to continuously improve. This involves the necessity to monitor and analyze processes on an ongoing basis, as well as to react quickly, for example, by introducing a new type of product. Developing new products is one of the key factors for progress and competitive advantage in any country. Companies around the world are facing changes in both production technology and service organization. The product life cycle has never been as short as it is now, so developing a new commodity is one of the most important business tasks (Silineviča et al., 2016). From a macroeconomic perspective, new products are important for generating employment and economic growth, technological advances and generally higher standards of living (Bhuiyan, 2011). From a company's perspective, new product development is essential to remain competitive, survive and prosper (Guimaraes et al., 2019).

Product development is the process by which an organization transforms market and technical opportunities into valuable information for commercial production (Clark et al., 1991). Unlike business processes that have clear characteristics and are designed to produce predictable results, product development aims to create something new. It requires creativity, innovation, and is non-linear and iterative (Kline, 1985; Browning et al., 2006).

The process of bringing new products to market is a key area of research and business practice. First, while earlier literature research on new product development focused mainly on durable goods (Barczak, 2012), the global economy has shifted from being commodity-based to more service-oriented (Eichengreen, Gupta, 2013). Second, it is now common practice for companies to offer customers multiple options for accessing a product in order to meet different customer needs and maximize market potential (Shi et al., 2016).

The ability to manufacture a product from design through production does not always guarantee sales. In the age of the Internet, globalization and unlimited access to information, it is not only customers who define their needs, it is also designers who create new ideas in the mind of the customer. Hence, for example, the concept of design management plays an important role in the process of new product development (Dziadkiewicz, 2013). In addition, developing innovative products requires openness and flexibility, the ability to manipulate different perspectives, and control the direction to ensure that new information is effectively integrated and implemented to generate product solutions (Chiang, Hung, 2014). Accordingly, one of the indispensable processes of new product development is modeling. It is an activity that must be performed to create one or more process models for a specific purpose, e.g., design, specification, analysis or control of a particular process (Vernadat, 1996). Developing a new product each time requires the selection of an appropriate model (Aguilar-Savén, 2004).

2. Literature review

The beginning of literature reports on the issue of new product development (NPD) dates back to the 1960s (De Silva, Rupasinghe, 2016). To date, there are many different definitions of a new product (Cooper, 1999, 2001; Cooper et al, 1997; Ozer, 1999; Tracey, 2004). One of them, proposed by Cooper, defines it as a specific product that has been on the market for up to three years, which may be subject to further improvements and/or expansions. All definitions, however, have one thing in common, i.e., they define a new product as one that has not previously been produced by a company (Owens, 2009).

A product that is new to the manufacturer is characterized by a changed, improved design, construction, material composition, the use of a new material, a new technological process or a new way of serving the customer. A product perceived as new to the consumer is a commodity that satisfies a new need or better satisfies an existing need (Mruk, Rutkowski, 1999). A new product is undoubtedly essential to an organization's business continuity. Businesses are expected to innovate and develop new products in accordance with ever-changing customer tastes and needs (Doorasamy, 2017).

A new product offers the organization the greatest opportunity to increase revenue and profitability (Guimaraes et al., 2019). The main goals of the product development process are to minimize life-cycle costs, maximize product quality, and maximize customer satisfaction and flexibility, and minimize lead time (Mazumdar, 2001). The product development process can be divided into two main processes, i.e. product development and product production (Kušar et al., 2004).

NPD is a complex process. Its complexity and risks are due to the presence of multiple phases of the NPD process and its many stakeholders, the complexities of the product under development, changing consumer demands, increased market globalization, extended supply chains and design networks (Guimaraes et al., 2019).

Despite extensive research on how to achieve NPD success, products that fail continue to be developed. Approximately 46% of resources allocated to NPD are spent on products that are discontinued or do not provide an adequate financial return (Bhuiyan, 2011).

Among the biggest challenges faced by companies in the aspect of new product development are the pace (time), meeting the requirements of the approved budget, and determining the best possible project management method (Rawat, Divekar, 2014).

One of the main goals of any development program should be to get the right product or service to the market or to the customer as quickly as possible. However, this can limit the chance of a competitor gaining an advantage and thus gaining an early market position (Owens, 2009; Owens, Atherton, 2018).

The cost of development, whether large or small, puts a strain on an organization's cash flow (Hultink, Hart, 1998). For example, marketing functions can consume enormous resources determining which products should be offered in which markets and at what price. Imposed constraints on the scope of a new product, usually stem from a combination of the company's mission or strategy and the attractiveness of the market (Cooper, Kleinschmidt, 2000).

According to a research report published by the Product Development and Management Association (Pandey et al., 2019), despite the use of new methods and techniques, the success rate of NPD in marketing organizations in the US remains stagnant (about 58%). To overcome this stagnation and improve NPD success, marketing and management researchers have proposed solutions in the form of new practices. For example, some scholars call for greater emphasis on the design and commercialization of new products (Kaul, Rao, 1995; Srivastava et al., 2009). Others (Henard, Szymanski, 2001; Pattikawa et al., 2006) focus on the performance of new products. Change management is also addressed (Pandey, Jaiswal, 2014). In contrast to marketing researchers, management experts focus on product innovation, product development decisions, innovation terminology and NPD-related factors (NPD speed and new product performance) (Pandey et al., 2019).

Rosenfeld et al (2006) define the product development process as "a set of activities in which it seeks to meet market needs and the capabilities and limitations of the technology (...) to achieve the design specifications of the product and its manufacturing process (...) includes post-market follow-up activities". Several approaches can be identified for these activities, defined according to the type of company or product. Various models are thus characterized (Pereira, 2018). New product development is a complex process, involving high risk. However, the success of carrying out such a process is associated, as research shows, with a systematic product development process (Cooper, 2008b).

Product development aims to generate functional and productive products. The literature contains numerous frameworks for the product development process. These models are abstract descriptions of activities and recommendations that support the product developer. Process models are usually created in a generic and theoretical form to fit a wide range of possible development situations. Each model must be tailored to a specific situation (Riesener et al., 2019).

Process models consist of distinct phases and structured workflows defined at the beginning of product development. The starting point for product development is usually planning. This is followed by the conceptual phase, during which requirements are specified and ideas are refined. Determining the basic concept of a product concerns defining its function and structure. In the design phase, product elements are developed technically and economically. The final stage of the process is the development phase (Riesener et al., 2019).

Three concepts are inseparable from the product development process, i.e. innovation, development and novelty. Innovation can be considered a unit of technological change and invention (if any), which is part of the innovation process (Harborne, Johne, 2003). The development of a new product does not necessarily include innovation, meaning that new products are characterized by the introduction of minor or major changes to existing products (Noke, Radnor, 2004). Novelty can include works (such as original innovations or products that are new to the world or to the company), additions, improvements and changes, repositioning of the product (such as innovative ways to use it in a different market segment or possibly the use of branding) or simply cost reductions (lower price or improved cost of living) (Owens, 2009).

Numerous examples of research on NPD models can be found in the literature. Based on the conclusions drawn from these publications, it can be said that it is not possible to create one definitive NPD model applicable to every situation. For this reason, many authors propose various classifications of the available models. For example, Saren (1984) in his work proposed five categories of NPD process models available at the time, grouping them into staged, activity stage, decision stage, conversion process and response. Other authors, on the other hand, propose various kinds of modifications, thus creating hybrids based on already known models, e.g. Noke, Radnor (2004) in their study used the staged (phase) development model from the 1960s as a starting point for comparison with some of the NPD process model ideas that developed from the late 1980s to the early 2000s. There are many different ways to model the NPD process, and each way involves its own strengths and weaknesses.

3. General models of NPD

We can find assessments of the implementation of both the new product development process itself and the application of various types of models as early as the literature of the 1990s (De Silva, Rupasinghe, 2016). Interestingly, most of the analysis is concentrated in the marketing or management domain, while little attention has been paid to product engineering (Cooper, 1994; De Silva, Rupasinghe, 2016).

There are three basic approaches in the implementation of deployed products, i.e., first-generation (functional structure), second-generation (integrated, concurrent process) or third-generation (model focused on speed, flexibility and customer requirements) processes. All three generations belong to stage-gate models i.e. processes of transition from idea to launch, consisting of separate stages, where each stage is preceded by a decision point to move to the next (go) or end stage (kill) or gate.

The stage-gate model developed by Cooper became fundamental to further developments, being modifications or extensions of it (Cooper, 1994). Virtually all models developed before 1995 were sequential, which is why they are referred to as “waterfall” in the literature. Product development is divided in them into a sequence of predefined phases, such as feasibility, planning, design, build, test, manufacture and support, with some overlap between each phase or stage. However, this type of work affects the appearance of delays between business requirements and technology delivery. Changing customer requirements during this time, for example, results in final products that often no longer meet current needs (Ottosson, 2019). The latest approach related to the NPD issue is network models (Matusek, 2013). These models, not only design products, but take into account the needs of the consumer and make companies far more open to innovation (De Silva, Rupasinghe, 2016).

Table 1 presents the different generations of NPD models. The early generations of stage processes were largely driven by engineering, which in practice meant that they were based almost exclusively on physical product design and development. As an integral part of product development, next-generation systems incorporate the involvement of the marketing and manufacturing departments, and furthermore treat each stage as an interdisciplinary team effort. The first generation systems were sequential in nature, only the latest generation models assume parallel activities, process stages can overlap, which improves flexibility and reduces unnecessary time lapses between process stages (Cooper, 1994). In addition, third-generation models allow conditional transitions between stages (fuzzy stage-gate).

Different approaches can be found among the various generations of models described in the literature; for example, Peters et al. (1999) state that typical models are aimed at management, design or have been developed for specific industry needs. Modern models, on the other hand, assume a collaborative attitude (Yang, Yu, 2002). Some of them assume collaboration using information technology, mainly simulation methods and virtual prototyping, others, close cooperation between the end user and the inventor.

Table 1.
Review of NPD models in the literature

NPD models	Publications
Stage-gate: Cooper, 1994 1st-3rd generation	Cooper, 1983; 1990; 1994 De Silva, Rupasinghe, 2016
Bass diffusion model: Bass, 1969	Bass et al., 1994 Bass, 2004 Ansari et al., 2010 Wu et al., 2015 Peres et al., 2010 Mahajan, Muller, 1996 Chung, 2011 Shi, 2016
Concurrent process models	Hambali, 2009 Bhuiyan et al., 2006 Smith, Morrow, 1999 Nelson et al., 2016 De Silva, Rupasinghe, 2016
Total design model: Pugh, 1991	Pugh, Moreley, 1988a, 1988b Pugh, 1991 Owens, 2009
Design for Manufacture and Assembly (DFMA): Boothroyd, 1994	Matusek, 2013 Yin, Hou, 2019 Kishore, Arunkumar, 2020
Multiple convergent model: Hart, 1995	Hart, Baker, 1994 Owens, 2009 Owens, Atherton, 2018

Cont. table 1.

Generic model: Peters, 1999	Peters et al., 1999 Matusek, 2013
Product and cycle time excellence model	Pittiglio, Rabin, McGrath, 1994 Owens, 2009
Supplier integrated model: Handfield, 1999	Handfield et al., 1999 De Silva, Rupasinghe, 2016
Next Generation Idea-to-Launch System: The Triple A System	Cooper, 2008a; 2014
Open innovation model	Cooper, 2008a Chesbrough, Bogers, 2014 Bogers et al., 2017 Zhu, et al., 2019
Collaborative product development models	Nambisan, 2002 De Silva et al., 2018
Electronic NPD (E-NPD): Yang and Yu, 2002	Yang, Yu, 2002
Virtual customer integration	Füller et al., 2010 De Silva, Rupasinghe, 2016 Hemetsberger, 2007 Nambisan, 2002
Virtual New Product Development Team	Aubert, Kelsey, 2003 Martins et al., 2004 Badrinarayanan et al., 2008 De Silva, Rupasinghe, 2016

Source: own elaboration.

4. Overview of NPD research in the chemical sector

A review publication by Kalluri, Kodali (2014) on a review of new product development research conducted between 1998 and 2009 shows that most of the studies described then could be assigned to the categories of other, not applicable or general. In turn, the most favored research sector was the automotive industry (about 15%), while much less attention, only about 1-5%, was given to research in the aerospace, food, machinery, apparel or chemical sectors. The total number of publications on the chemical sector during this period was only 34 (Kalluri, Kodali, 2014). The literature analysis also shows that only a few of the publications address topics related in some way to NPD modeling in the chemical industry. Of which, the topics are more about systems, tools used in product development, rather than analysis of a specific NPD model that could be used throughout the process.

In the chemical industry, product development can be technology-driven and demand-driven. The selection of chemical product ideas should be based not only on an analysis of what is possible to produce, but also on an analysis of what the market would like to buy (Hill, 2009). From the consumers' point of view, the properties of the final product are more important than the chemical composition. To meet consumer expectations, both consumer needs and technologies must be transformed into new product design and development (Charpentier, McKenna, 2004).

Most chemical products are designed using trial-and-error techniques based on experimentation, making NPD in the chemical industry more iterative. This often involves generating a huge number of chemical components, and this means that the search area can be very large. It is therefore reasonable to look for decision support tools to facilitate the selection of necessary components (Lee, 2017).

In the chemical industry, NPD can be divided into three types. First, new products can be inspired by new chemical ingredients, information from exhibitions and conferences, market reports or published articles. Based on such information, product prototypes are created and then evaluated. The second type of products is created using reverse engineering. Third, products can also be marketed, and after studying customer needs, marketers redefine product concepts. One possible tool to support decision-making processes in the above three types of NPD is case-based reasoning (CBR). It allows searching for similar, previous NPD cases. Thus, it provides knowledge of problems that have occurred and reduces development time. One disadvantage of using CBR to solve NPD problems is that CBR lacks the ability to capture the ambiguity of human expression in product attributes, which are often described in qualitative terms (Lee, 2017).

It is believed that the subjective evaluation of sensory attributes of chemical products can also be managed through the Analytic Hierarchy Process (AHP), also known as Saaty's eigenvector method. It is a tool for making multi-criteria decisions when both qualitative and quantitative aspects of a decision need to be considered. It is an effective method for gathering expert knowledge in solving complex decision-making problems and has become one of the most widely used approaches for generating concepts and evaluations during NPD. However, the subjective evaluation, selection and preferences of decision makers affect the final results. A more accurate description can be obtained using an extension of this method, the so-called fuzzy analytic hierarchy process (fuzzy-AHP), where evaluation criteria weights are applied (Lee, 2017).

A method to solve the problem of ingredient composition in chemical product development was also proposed by Lee (2017). The knowledge-based product development system (KPDS), is a hybrid of CBR (case-based reasoning) and fuzzy-AHP. In this intelligent system, linguistic preferences for products are matched with similar comparisons, resulting in increased ease of formulating desired products. According to the author, compared to the pure CBR approach, the KPDS is more effective, as a systematic method for determining the relative importance of product attributes is provided. Moreover, the vagueness of human expression and quantitative values were also taken into account using fuzzy-AHP. In addition, KPDS is equipped with two functions to improve the sensitivity of the results (Lee, 2017). Another example of a hybrid model can be found in an article by Choy et al. (2016). Aimed at supporting sustainable consumption and production from product development to chemical product manufacturing processes, the model integrates an operational strategy model with artificial intelligence, including CBR and fuzzy logic. The development of chemical products becomes more efficient, the number of trials and the amount of chemical waste generated are minimized.

The next example proposed by Sapuan concerns a concurrent engineering design system for polymer-based automotive composites (Sapuan, Abdalla, 1998). The system involves the integration of various concurrent engineering tools, such as a knowledge-based system (KBS), solid modeling, material database and design analysis tools. The material selection process is based on a set of specific criteria and constraints related to the specifications of the desired material and component design. Material selection must be dictated by meeting all of the set criteria/constraints. Violation of any of them determines the rejection of that material. According to the author's analysis, the selection of a polymer-based composite component system resulted in weight and cost reductions of 31 and 53%, respectively, compared to a steel counterpart (Hambali, 2009; Kalluri, Kodali, 2014).

In summary, numerous examples of various types of NPD models can be found in the literature. However, no model dedicated to the chemical industry was found. The analysis of the literature allowed only the identification of typical, for this industry, tools. Therefore, in the following part of the work, the models characterized above were evaluated for applicability to chemical product development processes. For this purpose, one of the techniques typical of the industry was used. Based on general and key factors in the NPD process, it was determined which of the models could best serve as a benchmark. The results obtained were related to a selected example of NPD in the chemical industry.

5. Key factors determining the success of new product development

There are many factors that affect the performance of a company. However, only a few enable success, so they are fundamental to the company and are called critical success factors (CSFs). The process of identifying CSFs is based on the manager's current point of view. By aggregating CSFs from an individual's point of view and identifying existing relationships, it is possible to discover exactly which areas and activities require attention due to their criticality (Rocha, Delamaro, 2012).

The AHP method was proposed by Saaty in the early 1970s. It is classified as one of the best known, safest and most widely used multi-criteria decision analysis. AHP can use both qualitative and quantitative factors to create a hierarchical structure in the decision-making process. This can help select the best option based on the selection criteria presented in the model (Chan et al., 2019). These factors determine which model is more appropriate for the industry under study. The evaluation criteria are determined with expert support and are also based on literature research, pertaining to the industry sector under study.

Thus, first, based on literature data, an attempt was made to identify CSFs specific to the chemical industry. Only one publication addressing this topic was found in the literature. Namely, Cooper, Kleinschmidt (1993) analyzed 21 major chemical companies in 4 countries (the United States, Canada, the United Kingdom and Germany). The data was collected over a period of two years. The performance of a new product was evaluated on a variety of measures, including an assessment of profitability, technological success, annual sales revenue and market share (domestic and international), and the impact of sales and profit on the company. Based on this data, the authors determined six main factors affecting the success of new product development. Table 2 shows their characteristics.

Table 2.
CSF characteristics of NPD process in the chemical industry

Critical success factors	Characteristics
Quality of execution of the activities that make up the innovation process (Q)	The quality of chemical project implementation, where key activities include: - detailed market research, - pilot production, - analysis of pre-commercial activities, - preliminary market assessment, - trial sales, - preliminary review
Early and clear definition of the project and product (P)	- definition sets clear objectives for the development phase, - defining the product and project early in the project and before entering the development phase (target market, product concept, benefits to be delivered, positioning strategy and product requirements)
A strong team leader with a responsible, multidisciplinary team (L)	- project leader – timely implementation of a project from idea to launch, successfully completed, - a cross-functional team drawn from different functions within the company (as opposed to each function or department doing its own part of the project) – project implementation from start to finish
Close link between sources of ideas and project results (S)	- the most effective projects are based on ideas that come from customers or are technology-based, where the idea comes from the technology and/or lab (the most popular), - projects based on concepts are slightly less effective - taken from competitors
Elements related to marketing – qualitative and quantitative (M)	- the quality of the formal launch including customer service and technical support, - the quality of the sales force, - product availability (reliability of delivery and sufficient available production), - lack of importance of advertising and promotion in industrial, higher technology, large products
International orientation (G)	- global product (designed for the world market), - foreign competition, - least successful new product strategy – nearest-neighbor approach, i.e., products targeting the domestic market and one or more neighboring markets

Source: elaboration based on Cooper, Kleinschmidt, 1993.

Based on their research, Cooper, Kleinschmidt (1993) noted that the success of a new product is predictable and largely controllable. It is the project leader and the team who exercise control over the key variables that determine success. Significantly, the success factors for a new product are fairly universal. Most of the results of this chemical industry study were consistent with previous studies of new product success and failure. The author also noted how critical product innovation is to business success. With increasing competition at home and abroad, more and more companies are being forced to treat product development as a major component of their overall business strategy.

However, the CSFs presented here refers to research conducted almost 30 years ago. Thus, in the next step, general success factors specific to the new product development process were identified, based on an analysis of the literature compiled between 2005 and 2022. Table 3 presents their characteristics.

Table 3.

Characteristics of the critical success factors in NPD process (selected literature examples)

Critical Success Factors	Publications
- high product quality, - increased design capabilities, - short product development cycle time, - market responsiveness, - cost management, - advanced technology applications, - innovation	De Silva, Rupasinghe, 2016
- a clearly defined target market, - implementation of quality standards, - clear project objective, - solving problems at an early stage, - internal communication within the team, - on-time delivery, - adequate time for launch, - competitive cost of the product	Sun, Wing, 2005
- timely completion, - cost, - quality, - customer preferences, - technical advantage, - strategic alignment, - proper execution of projects, - coordination between projects, - company reputation and ethical conduct, - correct definition of project scope, - customer relations	Iamratanakul et al., 2014
- top management support, - the link between new product strategies and business visions, - cross-functional teams with flexible and mutual support, - timing of new product launches, - satisfaction of customer demand, - creativity and innovation, - cost of production, - integration and application of R&D-related equipment and technology, - application of database management system, - excellent planning and monitoring, - complete quality management system, - use of management tools	Yeh et al., 2014
- shorter time in the development process, - lower product manufacturing cost, - products with greater customization, more relative benefits and added value, - companies with greater internal coordination and external cooperation, - product introduction time, - competitors with less aggressive responses	Chi-Jyun, Shiu, 2008

Cont. table 3.

- marketing skills, - product strategy, - technology sources, - company skills, - project leader skills, - functional integration, - project team organization, - product development performance	Öztürk, 2018
- cost and budget management, - time and deadline management, - product positioning, - customer needs fulfillment, - organizational alignment, - characteristics of the development team, - work process (development process), - organization and management of the work environment	Rocha, Delamaro, 2012
- senior management involvement, - early customer engagement, - external cooperation beyond customers, - alignment between NPD and strategy, - appropriate degree of formalization, - cross-functional and cross-departmental cooperation, - creative organizational culture, - project management capabilities	Florén et al., 2018

Source: own elaboration.

6. Results and discussion

Analysis of the collected data made it possible to select the five general CSFs most frequently mentioned in recent literature, i.e. time (T), cost (C), innovation (I), technology (E) and integration (N) – understood as coordination of tasks, cooperation or good communication. Organizations need to work at very high levels of efficiency, optimizing existing resources, in order to achieve and maintain their position in the market. This is due to increased competitive pressures caused by technological advances. Consumers are increasingly demanding and aware, and their expectations, needs and tastes are changing very rapidly. Today, companies are reinventing their development processes to become faster (including shorter time-to-market) while constantly innovating even in the smallest components. This involves increasing R&D costs and rising capital costs. In order to optimize the product success rate, marketing, manufacturing and design functions must also be integrated.

Using the basic 9-point scale (Table 4) defined by Saaty (1980) in the next step, the value of CSF priorities typical of the chemical industry was determined first (Table 5). The assumption was made that the importance of each criterion decreases in the order Q > P > L > G > M > S (cf. Table 2).

Table 4.
AHP scale for pairwise comparisons

Significance level	Definition
1	equally importance
3	moderate importance
5	strong importance
7	very strong importance
9	extreme importance
2, 4, 6, 8	moderate values

Source: Saaty, 1980.

Table 5.
Prioritization of CSFs concerning the chemical industry

	Q	P	L	G	M	S	Criteria weights (%)
Q	1	3	5	7	8	9	47,40
P	0,33	1	3	5	6	7	25,60
L	0,2	0,33	1	3	4	5	13,20
G	0,14	0,2	0,33	1	2	3	6,40
M	0,12	0,17	0,25	0,50	1	2	4,30
S	0,11	0,14	0,20	0,33	0,50	1	3,00

Note. Q – quality, P – project and product, L – leader and team, G – globalization, M – marketing, S – sources.

Source: own elaboration.

In the next step, taking into account the factors relevant to the chemical industry, the CSF priority value was determined along with the parameters selected based on the analysis of recent literature (Table 6). The following assumptions were made:

- the most relevant CSF for the chemical industry (Q = 9) has a higher value compared to the most relevant general CSFs (T, C, I = 8)
- the next two factors, i.e., technology (E) and integration (N), are slightly less important (4) than project and product definition (P = 7) or leader and team (L = 5), important in the chemical industry
- the least importance was assigned to the parameters G (3), M (2) and S (1).

Table 6.
Prioritization of CSFs

	Q	I	T	C	P	L	E	N	G	M	S	Criteria weights (%)
Q	1	2	2	2	3	5	6	6	7	8	9	23,40
I	0,50	1	1	1	2	4	5	5	6	7	8	15,70
T	0,50	1	1	1	2	4	5	5	6	7	8	15,70
C	0,50	1	1	1	2	4	5	5	6	7	8	15,70
P	0,33	0,50	0,50	0,50	1	3	4	4	5	6	7	10,70
L	0,2	0,25	0,25	0,25	0,33	1	2	2	3	4	5	5,50
E	0,17	0,2	0,2	0,2	0,25	0,50	1	1	2	3	4	3,70
N	0,17	0,2	0,2	0,2	0,25	0,50	1	1	2	3	4	3,70
G	0,14	0,17	0,17	0,17	0,2	0,33	0,50	0,50	1	2	3	2,60
M	0,12	0,14	0,14	0,14	0,17	0,25	0,33	0,33	0,50	1	2	1,90
S	0,11	0,12	0,12	0,12	0,14	0,20	0,25	0,25	0,33	0,50	1	1,40

Note. Q – quality, I – innovation, T – time, C – cost, P – project and product, L – leader and team, E – technology, N – integration, G – globalization, M – marketing, S – sources.

Source: own elaboration.

It should be noted that the weight of the quality criteria is clearly more relevant than the other criteria, as it is an important characteristic associated with the chemical industry. Nevertheless, given current trends and conditions, innovation processes, time and cost are also of great importance. One of the least important meanings is globalization due to the fact that the introduction of modern information technology makes the process almost automatic. Likewise, the importance of the elements involved in bringing a product to market and the source of ideas in developing new projects/products are not as significant in relation to the other factors selected. The importance of these criteria shows the evolution of NPD and the adaptation to the actual needs of companies in making faster decisions in a competitive market.

7. Summary

An analysis of the existing literature shows that despite the creation of many general models for new product development, there is no single, specific one that can form the basis for product development in any industry. Each company, deciding to develop and introduce new products, should define its needs and choose the most suitable model for the process. In the literature one can find examples of models dedicated to, for example, the apparel industry, the furniture industry or the automotive industry. However, no attempt has been made to verify models defined for the chemical industry.

The chemical industry is part of the processing industry sector and one of the world's key industries. The current structure of the chemical industry can be characterized by various products starting from oil and gas through petrochemicals, chemicals, polymers, special additives or active ingredients. These products are used in almost every area of life. Product life cycles are often longer compared to other industries and products. Products developed decades ago are still important raw materials sold on the market today. The chemical industry serves many other industries as a supplier of raw materials and often acts as a good indicator of overall economic development.

For a good understanding of the requirements and drivers of the chemical industry, the development of the chemical market and the trends involved must be carefully analyzed. Among the biggest changes associated with 21st century trends are globalization (the growth of global trade), consolidation (the rise of ever larger and more complex corporations), commoditization and margin pressure (cost reduction e.g. through restructuring or outsourcing), innovation (use of new technologies, such as biotechnology, nanotechnology, artificial intelligence), legislation (mainly EU legislation, precise documentation, compatibility of standards) and sustainability (e.g., efficient management of natural resources).

In general, chemical products are primarily not designed and developed as a single product, but as product lines or portfolios. Commodity chemical products (e.g., petrochemicals, basic chemicals and some polymers) tend to be manufactured and sold to mass markets in large volumes and at low unit values. In contrast, specialty products, such as nutritional and agricultural products, are sold in specialized markets, in smaller quantities and at higher unit values.

Both the literature data and the results of the analysis conducted indicate that there is no single, ideal NPD model that can be applied to different industries and products. In this paper, two approaches were used, i.e. using CSFs general and specific to the chemical industry. The results also indicate several trends that should be taken into account in further analysis of the models for their application to specific industries or products, i.e.:

– the number of different types of models described in the literature indicates that it would be beneficial to carry out a classification of them, e.g. by creating a database of models, taking into account their characteristics, or different groups of products or industries. For example, among the models discussed, some were strongly oriented on the quality parameter and the product definition process, others on the use of various types of new technologies. This would make it easier for managers to look for specific solutions;
– the analysis of the results shows that a better solution in the NPD model selection process is to use CSFs dedicated to a particular industry. Which suggests that a more precise specification of CSFs would allow more accurate matching of the appropriate NPD model. It is therefore advisable for companies wishing to conduct this type of analysis to define CSFs according to their own guidelines in each case.

References

1. Aguilar-Savén, R.S. (2004). Business process modelling: review and framework. *International Journal of Production Economics, 90, 2,* pp. 129-149.
2. Ansari, S.M., Fiss, P.C., Zajac, E.J. (2010). Made to fit: how practices vary as they diffuse. *Academy of Management Review, 35, 1,* pp. 67-92.
3. Aubert, B.A., Kelsey, B.L. (2003). Further understanding of trust and performance in virtual teams. *Small Group Research, 34, 5,* pp. 575-618.
4. Badrinarayanan, V., Arnett, D. (2008). Effective virtual new product development teams: an integrated framework. *Journal of Business & Industrial Marketing, 23, 4,* pp. 242-248.
5. Barczak, G. (2012). The future of NPD/innovation research. *Journal of Product Innovation Management, 29, 3,* pp. 355-357.
6. Bass, F.M. (2004). A new product growth for model consumer durables. *Management Science, 50, 12,* pp. 1825-1832.

7. Bass, F.M., Krishnan, T., Jain, D.C. (1994). Why the Bass model fits without decision variables. *Marketing Science*, *13, 3,* pp. 203-223.
8. Bhuiyan, N. (2011). A framework for successful new product development. *Journal of Industrial Engineering and Management*, *4, 4,* pp. 746-770.
9. Bhuiyan, N., Thomson, V.J., Gerwin, D. (2006). Implementing concurrent engineering. *IEEE Engineering Management Review, 34, 3,* pp. 95-101.
10. Bogers, M., Zobel, A.K., Afuah, A., Almirall, E., Brunswicker, S., Dahlander, L., Frederiksen, L., Gawer, A., Gruber, M., Haefliger, S., Hagedoorn, J., Hilgers, D., Laursen, K., Magnusson, M.G., Majchrzak, A., McCarthy, I.P., Moeslein, K.M., Nambisan, S., Piller, F.T., Radziwon, A., Rossi-Lamastra, C., Sims, J., Ter Wal, A.L.J. (2017). The open innovation research landscape: established perspectives and emerging themes across different levels of analysis. *Industry and Innovation*, *24, 1,* pp. 8-40.
11. Browning, T.R., Fricke, E., Negele, H. (2006). Key concepts in modeling product development processes. *Systems Engineering*, *9,* pp. 104-128.
12. Chan, H.K., Sun, X., Chung, S.H. (2019). When should fuzzy analytic hierarchy process be used instead of analytic hierarchy process? *Decision Support Systems*, *125*, 3-5, doi: 10.1016/j.dss.2019.113114.
13. Charpentier, J.C., McKenna, T.F. (2004). Managing complex systems: some trends for the future of chemical and process engineering. *Chemical Engineering Science*, *59,* 8-9, pp. 1617-1640.
14. Chesbrough, H., Bogers, M. (2014). Explicating open innovation: clarifying an emerging paradigm for understanding innovation. In: H. Chesbrough, W. Vanhaverbeke, J. West (Eds.), *New frontiers in open innovation* (pp. 3-28). Oxford: Oxford University Press.
15. Chiang, Y.H., Hung, K.P. (2014). Team control mode, workers' creativity, and new product innovativeness. *R&D Management*, *44, 2,* pp. 124-136.
16. Chi-Jyun Cheng, C., Shiu, E.C. (2008). Critical success factors of new product development in Taiwan's electronics industry. *Asia Pacific Journal of Marketing and Logistics*, *20, 2,* pp. 174-189.
17. Choy, K.L., Choy, K.L., Ho, G.T.S., Lee, C.K.H., Lam, H.Y., Cheng, S.W.Y., Siu, P.K.Y., Pang, G.K.H., Tang, V., Lee, J.C.H., Tsang, Y.P. (2016). A recursive operations strategy model for managing sustainable chemical product development and production. *International Journal of Production Economics*, *181*, pp. 262-272.
18. Chung, J. (2011). Investigating the roles of online buzz for new product diffusion and its cross-country dynamics. *Journal of Business Research*, *64, 11*, pp. 1183-1189.
19. Clark, K.B., Fujimoto, T. (1991). *Product development performance: strategy, organization, and management in the world auto industry*. Boston: Harvard Business School Press.
20. Cooper, R.G., Kleinschmidt, E.J. (2000). New product performance: what distinguishes the star products? *Australian Journal of Management*, *25, 1*, pp. 17-46.

21. Cooper, R.G. (1990). Stage-gate systems: a new tool for managing new products. *Business Horizons*, *33, 3,* pp. 44-54.
22. Cooper, R.G. (1994). Third-generation new product processes. *Journal of Product Innovation Management*, *11, 1,* pp. 3-14.
23. Cooper, R.G. (1999). From experience: the invisible success factors in product innovation. *Journal of Product Innovation Management*, *16, 2,* pp. 115-133.
24. Cooper, R.G. (2001). *Winning at new products: accelerating the process from idea to launch*. Cambridge: Perseus Publishing.
25. Cooper, R.G. (2008a). Perspective: the stage-gates® idea-to-launch process – update, what's new, and NexGen systems. *Journal of Product Innovation Management*, *25, 3,* pp. 213-232.
26. Cooper, R.G. (2008b). What leading companies are doing to re-invent their NPD processes. *PDMA Visions Magazine*, *32, 3,* pp. 6-10.
27. Cooper, R.G. (2014). What's next? After Stage-Gate. *Research Technology Management*, *57, 1,* pp. 20-31.
28. Cooper, R.G., Edgett, S.J., Kleinschmidt, E.J. (1997). Portfolio management in new product development: lessons from the leaders-I. *Research Technology Management*, *40, 5,* pp. 16-28.
29. Cooper, R.G., Kleinschmidt, E.J. (1993). New-product success in the chemical industry. *Industrial Marketing Management*, *22, 2,* pp. 85-99.
30. De Silva, R.K.J., Rupasinghe, T.D. (2016). Characterization of new product development (NPD) models applicable to enhance the overall performance of the apparel industry. *International Journal of Textile and Fashion Technology*, *6, 3,* pp. 1-14.
31. De Silva, R.K.J., Rupasinghe, T.D., Apeagyei, P. (2018). A collaborative apparel new product development process model using virtual reality and augmented reality technologies as enablers. *International Journal of Fashion Design, Technology and Education*, *12, 1,* pp. 1-11.
32. Doorasamy, M. (2017). Product portfolio management best practices for new product development: a review of models. *Foundations of Management*, *9, 1,* pp. 139-148.
33. Dziadkiewicz, A. (2013). Rozwój nowego produktu poprzez wykorzystanie koncepcji zarządzania designem. *Roczniki Naukowe Wyższej Szkoły Bankowej w Toruniu*, *12,* pp. 355-369.
34. Eichengreen, B.B., Gupta, P. (2013). The two waves of service-sector growth. *Oxford Economic Papers*, *65, 1,* pp. 96-123.
35. Florén, H., Frishammar, J., Parida, V., Wincent, J. (2018). Critical success factors in early new product development: a review and a conceptual model. *International Entrepreneurship and Management Journal*, *14, 2,* pp. 411-427.

36. Füller, J., Faullant, R., Matzler, K. (2010). Triggers for virtual customer integration in the development of medical equipment – from a manufacturer and a user's perspective. *Industrial Marketing Management, 39, 8,* pp. 1376-1383.
37. Guimaraes, T., Paranjape, K., Walton, M. (2019). An expanded model of success factors for NPD performance. *International Journal of Innovation and Technology Management, 16, 7,* pp. 1-29.
38. Hambali, A, Sapuan, S.M., Ismail, N., Nukman, Y., Abdul Karim, M.S. (2009). The important role of concurrent engineering in product development process. *Pertanika Journal of Science & Technology, 17, 1,* pp. 9-20.
39. Handfield, R.B., Ragatz, G.L., Kenneth, P., Monczka, R. (1999). Involving suppliers in new product development. *California Management Review, 42, 1,* pp. 59-82.
40. Harborne, P., Johne, A. (2003). Creating a project climate for successful product innovation. *European Journal of Innovation Management, 6, 2,* pp. 118-132.
41. Hart, S.J., Baker, M.J. (1994). The multiple convergent processing model of new product development. *International Marketing Review, 11, 1,* pp. 77-92.
42. Hemetsberger A., Godula, G. (2007). Integrating expert customers in new product development in industrial business – virtual routes to success. *Innovative Marketing, 3, 3,* pp. 28-39.
43. Henard, D.H., Szymanski, D.M. (2001). Why some new products are more successful than others. *Journal of Marketing Research, 38, 3,* pp. 362-375.
44. Hill, M. (2009). Chemical product engineering – the third paradigm. *Computers and Chemical Engineering, 33, 5,* pp. 947-953.
45. Hultink, E.J., Hart, S. (1998). The world's path to the better mousetrap: myth or reality? An empirical investigation into the launch strategies of high and low advantage new products. *European Journal of Innovation Management, 1, 3,* pp. 106-122.
46. Iamratanakul, S., Badir, Y., Siengthai, S., Sukhotu, V. (2014). Indicators of best practices in technology product development projects. *International Journal of Managing Projects in Business, 7, 4,* pp. 602-623.
47. Kalluri, V., Kodali, R. (2014). Analysis of new product development research: 1998-2009. *Benchmarking: An International Journal, 21, 4,* pp. 527-618.
48. Kannegiesser, M., Günther, H.O., van Beek, P., Grunow, M., Habla, C. (2009). Value chain management for commodities: a case study from the chemical industry. *OR Spectrum, 31, 1,* pp. 63-93.
49. Kaul, A., Rao, V.R. (1995). Research for product positioning and design decisions: an integrative review. *International Journal of Research in Marketing, 12, 4,* pp. 293-320.
50. Kennedy, M.N. (2004). The Toyota product development system. *Machine Design, 76, 9,* p. 152.
51. Kishore, M.A., Arunkumar, S. (2020). DFMA and sustainability analysis in product design. *Journal of Physics.* Conference Series, doi: 10.1088/1742-6596/1455/1/012028.

52. Kline, S.J. (1985). Innovation is not a linear process. *Research Management, 26*, pp. 36-45.
53. Kušar, J., Duhovnik, J., Grum, J., Starbek, M. (2004). How to reduce new product development time. *Robotics and Computer-Integrated Manufacturing, 20, 1,* pp. 1-15.
54. Lee, C.K.H. (2017). A knowledge-based product development system in the chemical industry. *Journal of Intelligent Manufacturing, 30, 3,* pp. 1371-1386.
55. Mahajan, V., Muller, E. (1996). Timing, diffusion, and substitution of successive generations of technological innovations: the IBM mainframe case. *Technological Forecasting and Social Change*, *51*, *2*, pp. 109-132.
56. Martins, L.L., Gilson, L., Maynard, M.T. (2004). Virtual teams: what do we know and where do we go from here? *Journal of Management, 30, 6,* pp. 805-835.
57. Matusek, M. (2013). Rozwój nowego produktu w przedsiębiorstwach środowiska produkcyjnego – konstrukcja na zamówienie (engineering-to-order ETO). *Zeszyty Naukowe Politechniki Śląskiej, Organizacja i Zarządzanie*, *63*, pp. 247-260.
58. Mazumdar, S.K. (2001). *Composites manufacturing: materials, product, and process engineering*. Boca Raton: CRC Press.
59. Mruk, H., Rutkowski, I. (1999). *Strategia produktu*. Warszawa: PWE.
60. Nambisan, S. (2002). Designing virtual customer environments for new product development: toward a theory. *Academy of Management Review, 27, 3,* pp. 392-413.
61. Nelson, R.G., Azaron, A., Aref, S. (2016). The use of a GERT based method to model concurrent product development processes. *European Journal of Operational Research, 250, 2,* pp. 566-578.
62. Noke, H., Radnor, Z.J. (2004). Navigating innovation: a diagnostic tool supporting the process. *Journal of Manufacturing Technology Management*, *15, 2*, pp. 172-183.
63. Ottosson, S. (2019). *Developing and managing innovation in a fast changing and complex world: benefiting from dynamic principles*. Cham: Springer
64. Owens, J.D. (2009). Modeling the new product development process: the value of a product development process model approach as a means for business survival in the 21st century. In: D. Jemielniak, J. Kociatkiewicz (Eds.), *Handbook of research on knowledge-intensive organizations* (pp. 208-227). Hershey/New York: Information Science Reference.
65. Owens, J.D., Atherton, A.M. (2018). A conceptual analysis on the different approaches to new product development and the variables associated with modelling the process. In: K. Kumar, J.P. Davim (Eds.), *Design and optimization of mechanical engineering products* (pp. 1-23). Hershey: IGI Global.
66. Ozer, M. (1999). A survey of new product evaluation models. *Journal of Product Innovation Management*, *16, 1,* pp. 77-94.
67. Öztürk, D. (2018). The effect of success factors of new product development on product development performance: an application on white goods sector. In: A. Akinci (Ed.), *Interdisciplinary public finance, business and economics studies – volume I* (pp. 261-274). Berlin: Peter Lang.

68. Pandey, N., Jaiswal, A.K. (2014). Change management: a case of state power utility in India. *Asian Case Research Journal*, *18, 1,* pp. 61-80.
69. Pandey, N., Patwardhan, A., Swarnima, R., (2019). Four decades of new product development research: an integrative review. *International Journal of Product Development*, *23, 1,* pp. 1-14.
70. Pattikawa, L.H., Verwaal, E., Commandeur, H.R. (2006). Understanding new product project performance. *European Journal of Marketing*, *40*, *11-12,* pp. 1178-1193.
71. Pereira, J.A. (2018). *New application of product development model oriented to the R&D program of Brazilian electrical sector for planning a product project.* Curitiba: futuri9.
72. Peres, R., Muller, E., Mahajan, V. (2010). Innovation diffusion and new product growth models: a critical review and research directions. *International Journal of Research in Marketing*, *27, 2,* pp. 91-106.
73. Peters, A.J., Rooney, E.M., Rogerson, J., McQuater, R.E., Spring, M., Dale B. (1999). New product design and development: a generic model. *TQM Magazine*, *11*, *3,* pp. 172-179.
74. Pittiglio, T., Rabin, R., Todd, R., McGrath, M.E. (1994). *PRTM's third annual supply-chain performance benchmarking study executive summary: keys to supply chain excellence*. New York: Pittiglio Rabin Todd & McGrath.
75. Pugh, S. (1991). *Total design: integrated methods for successful product engineering*. Boston: Addison-Wesley Publishing.
76. Pugh, S., Moreley, I.E. (1988a). *Total design: some questions and some answers*. Glasgow: University of Strathclyde, Design Division.
77. Pugh, S., Moreley, I.E. (1988b). *Total design: towards a theory of total design*. Glasgow: University of Strathclyde, Design Division.
78. Rawat, S., Divekar, B.R. (2014). Assesing integration between project management with NDP process in heavy industrial components industry and developing a framework to align them. *Procedia Economics and Finance*, *11*, pp. 726-736.
79. Riesener, M., Dölle, C., Ebi, M., Tittel, J. (2019). Implications of service-related business models on product development processes. *Procedia CIRP*, *80*, pp. 756-761.
80. Rocha, H.M., Delamaro, M.C. (2012). Project/product development process critical success factors: a literature compilation. *Research in Logistics & Production*, *2*, pp. 273-293.
81. Saaty, T.L. (1980). *The analytic hierarchy process*. New York: McGraw-Hill.
82. Sapuan, S.M., Abdalla, H.S. (1998). A prototype knowledge-based system for the material selection of polymeric-based composites for automotive components. *Composites Part A: Applied Science and Manufacturing*, *29, 7,* pp. 731-742.
83. Saren, M.A. (1984). A classification and review of models of the intra-firm innovation process. *R&D Management*, *14*, *1,* pp. 11-24.
84. Shi, X., Bigdeli, A.Z., Li, F. (2016). An examination of NPD models in the context of business models. *Journal of Business Research*, *69, 7,* pp. 2541-2550.

85. Smith, R.P., Morrow, J.A. (1999). Product development process modeling. *Design Studies, 20, 3*, pp. 237-261.
86. Srivastava, V., Pandey, N., Reich, M.R. (2009). Identifying product attributes through conjoint analysis with special reference to Color Doppler. *Journal of Medical Marketing, 9, 4*, pp. 319-328.
87. Sun, H., Wing, W.C. (2005). Critical success factors for new product development in the Hong Kong toy industry. *Technovation, 25, 3*, pp. 293-303.
88. Tracey, M. (2004). A holistic approach to new product development: new insights. *Journal of Supply Chain Management, 40, 3*, pp. 37-55.
89. Vernadat, F. (1996). *Enterprise modeling and integration: principles and applications*. London: Chapman & Hall.
90. Wu, M. et al. (2015). Alleviating feature fatigue in product development based on the bass model. *Journal of Engineering, Design and Technology, 13, 3*, pp. 350-368.
91. Yang, J., Yu, L. (2002). Electronic new product development – a conceptual framework. *Industrial Management & Data Systems, 102, 4*, pp. 218-225.
92. Yeh, T.M., Pai, F.Y., Liao, C.W. (2014). Using a hybrid MCDM methodology to identify critical factors in new product development. *Neural Computing and Applications, 24, 3-4*, pp. 957-971.
93. Yin, C., Hou, S. (2019). *Application design for manufacture and assembly to improving product design and development performance*. Boston: ASABE Annual International Meeting, doi: 10.13031/aim.201900289.
94. Zhu, E.X., Xiao, Z., Dong, M.C., Gu, J. (2019). The fit between firms' open innovation and business model for new product development speed: a contingent perspective. *Technovation, 86-87, 6*, pp. 75-85.