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Editorial Office

Bialystok University of Technology
Wiejska 45A, 15-351 Bialystok, Poland
Phone: (+4885) 746 9825
Fax: (+4885) 663 1988
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Sub-disciplines in management sciences: criteria of sub-division in theory and research practice

Marek Matejun
Mengying Feng

ABSTRACT
This paper aims to identify the key criteria for distinguishing sub-disciplines in management sciences and evaluate their application in national and international science classifications. Documents from 16 different countries and areas were studied semantically. Triangulation was used to study 16 sub-discipline classifications and survey expert opinions among 31 representatives of management sciences from Poland and China to achieve the paper's purpose. Based on the results, the classifications use various criteria for categorising sub-disciplines, with the key criteria being (1) resources, (2) activity areas, (3) management concepts and methods, and (4) types of organisations. Meanwhile, the extent of their use is well in line with the expectations of the management sciences community representatives participating in the survey. The paper proposes a theoretical framework of 13 distinguishing criteria and characterises 16 classifications of sub-disciplines in management science from different countries. The theoretical considerations provide a good insight into the logic of creating a classification of sub-disciplines. They also provide a better description and understanding of the role of research specialisations in building the identity, organisation, and development of the management sciences community. The results align with a discussion on improving the classifications of management sciences' sub-disciplines. They are essential in identifying future and promising research specialisations within management sciences. They are helpful in the process of reviewing and/or placing particular research issues or problems in specific sub-disciplines of management sciences.

KEY WORDS
classification of science, management sciences, scientific sub-disciplines, research methodology

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Mengying Feng

Chongqing Jiaotong University, China
ORCID 0000-0001-5000-0293

Corresponding author:
e-mail: 1956882359@qq.com

Marek Matejun

University of Lodz, Poland
ORCID 0000-0003-4885-2344

Introduction

An important feature of management sciences is their strong thematic diversity and interdisciplinarity, showing links with other scientific disciplines (Sudoł, 2012, pp. 29–58). Zakrzewska-Bielawska (2012, pp. 15–17) emphasised that the areas of interest for management are constantly developing and expanding. Their problematic scope is so complex that no universally shared view on the matter has emerged to date. In this situation, scientific sub-disciplines, which express relatively narrow research specialisa-

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tions within management sciences, play an essential role in organising this diversity.

Research literature and practice propose many different classifications of management sciences' sub-disciplines. However, there is a lack of deeper reflection on the criteria for dividing and distinguishing these sub-disciplines in theory and research practice. This issue has been highlighted by many authors, e.g., Gorynia (2018, p. 15), who asked: "To what extent the classification postulates (how it should be) formulated by science scholars are respected in the classifications of science adopted for various purposes (how it is)?" The reviewer of this paper very accurately identified these approaches as positive (how it is) and normative (how it should be). With that in mind, this paper aims to identify the key criteria for distinguishing sub-disciplines in management sciences and evaluate their application in national and international science classifications.

The presented literature review was conducted to achieve the paper's purpose and operationalise the research problem into two research questions. Next, the author's research methodology is presented. Two research methods were used: document study and expert opinion survey. The following section analyses and interprets the research results. A scientific discussion answers the research questions, confronts the results with the literature on the subject, and points to the limitations of the conducted research. The conclusions formulate the main research findings and identify promising directions for further work on this topic.

1. Literature review and research questions

An essential feature of science understood as a systematic and comprehensive human endeavour in searching for objective and testable truth about reality (Wagner, 2022), is its great thematic diversity. One way to organise this diversity is to classify it, which involves designating and characterising specific components (fragments) of science in the form of disciplines and fields and their sub-disciplines/sub-fields/research specialisations based on objective, subjective, methodological, and linguistic (conceptual) differences (Pabis & Jaros, 2009; Baruch et al., 2022). Sub-disciplines are understood as formed and substantively distinguished due to the subject and purpose of research or permanent research specialisations within a specific discipline of science (Soliwoda, 2012, p. 337; Sudoł, 2014, p. 29). They are treated as collections of theoretical knowledge and sets of necessary skills (Jasińska, 2020) essential for solving thematically defined research problems.

The literature has long been debating the need and validity of science classification, including economic and management sciences, which involves two trends: to specialise and generalise or to differentiate (diversify) and unify (integrate) science (Fleming, 1880; Bronk & Majdański, 2009; Pabis & Jaros, 2010; Cyfert et al., 2014; Gorynia, 2018; Şengöz, 2020). Classification opponents mainly point to the lack of precise, uniform principles and criteria for the science division, an overly administrative approach to the issue, and the difficulties in capturing the entirety of scientific knowledge that results from the divisions. For example, Szarucki et al. (2022) noted that with a constantly growing bulk of knowledge in different sub-disciplines of management sciences, there is a growing demand for the consolidation, organisation, and synthesis of the existing knowledge.

Proponents point to the vital importance of science classification in organising the activities of scientific institutions, conducting advancement procedures in science, academic teaching, or distributing research funding. The division of science into thematic components also plays an essential role in creating and developing scientific communities and environments (Ross, 2021) and bibliometric analyses (Shu et al., 2019; Shu et al., 2020). Gorynia (2008, p. 40) also underlined the importance of the internal classification of sciences. However, he emphasised the challenge of classifying science, which is primarily determined by subjective factors, such as the opinion of prominent scholars or influential groups of scientists. As a result, there are varying solutions to classifying scientific specialities within different scientific communities and countries, making it very difficult to agree on these divisions internationally.

In this situation, the discussion on the type, scope, and application of specific criteria for distinguishing scientific sub-disciplines becomes of vital importance. In management sciences, this issue has been widely discussed by Sudoł (2012), suggesting that research issues in management sciences can be considered according to the following criteria:

- types of organisations: enterprises (production, commercial, service, finance, multi-entity, and others), nonprofit organisations, administrative, military and other units. An additional criterion may be the geographic range of conducted activ-

ity, allowing to distinguish, e.g., management problems considered locally, regionally, nationally, or in international markets;
- functions of management: planning, organising, motivating, and controlling;
- areas of activity/functions of the organisation, e.g., production management, logistics management, quality management, marketing management, personnel management, finance management, technological process management, etc.;
- processes: core, support, and service processes;
- resources: material and non-material resources, e.g., human, technical, knowledge and information, and financial resources;
- management level: strategic, tactical, and operational management;
- concepts and methods of management, e.g., system, project management, or change management.

Representatives of the Committee of Organisation and Management Sciences of the Polish Academy of Sciences (Cyfert et al., 2014) additionally propose the criterion of empirical engagement for distinguishing two primary research streams: the theoretical (oriented towards theorising, conceptualising, and possibly operationalising core issues) and the practical, which focuses on conducting empirical research to develop, verify and/or detail the theories of management sciences.

The criteria for distinguishing sub-disciplines are also influenced by the specific identity of management sciences (Trocki, 2005; Czakon, 2019). Since the discipline deals with the formation, operation, transformation, development, and interaction of organisations (Zakrzewska-Bielawska, 2012, p. 16), research work can be carried out on different levels of aggregation. Certo et al. (2010) pointed this out by distinguishing between research that is (1) primarily focused on individuals, teams, or groups (micro-level) and (2) primarily focused on organisations (meso-level). The macro level can further supplement this division, expressing research interest in inter-organisational relationships (Czakon, 2012) and even industry or sector-specific considerations.

Another important feature of management sciences is their relative youth and utilitarian nature, which translates into their greater dynamism than other scientific disciplines with already established traditions. Historically, management sciences began during the First and Second Industrial Revolutions (Turner, 2021). However, their evolution has undergone many phases (Lachiewicz & Matejun, 2012), conditioned strongly by technological development. This has enabled the development of simulation methods in management and is now increasing the importance of virtual organisations and remote management in digital environments (Vecchi et al., 2021; Durana et al., 2022). As a result, management becomes increasingly more virtualised, which leads to identifying reality as another criterion for subdividing sub-disciplines. In this case, management can be discussed in real, simulated, and virtual/digital environments.

A historical perspective on the development of management sciences also allows the introduction of two more criteria:
- prospects for development, associated with the tendency to raise the status of specific sub-disciplines and the emergence of new research specialisations within the management sciences (Kozłowski & Matejun, 2018, p. 140). Such an approach makes it possible, e.g., to distinguish declining, established, and emerging sub-disciplines;
- time, which refers to historical analyses (Agudelo et al., 2019; Wren & Bedeian, 2020) and discussions on future management trends (Tseng et al., 2019; Walker & Lloyd-Walker, 2019). This makes distinguishing such sub-disciplines as historical, contemporary, and future management possible.

Based on the above criteria, specific classifications of sub-disciplines in management sciences can be applied in scientific and research practice. They can be analysed from the point of view of specific characteristics, such as:
- application purposes, which may include, e.g., the separation and/or integration of the scientific community, the development of teams conducting research work, the evaluation of scientific activity carried out by higher education institutions, the identification of the activity profile and research interests of scientists, the conferment of specialisations within the framework of academic degrees, the distribution of funds for scientific research, the thematic classification of scientific journals and/or publications, support in the selection of journals in which management sciences researchers publish their research or the implementation of public statistics obligations;
- impact range, for which national and international classifications can be distinguished;
- number of classification levels adopted to distinguish sub-disciplines;

- number of distinguished sub-disciplines;
- embedding in a broader classification context. In this case, general breakdowns, which are part of broader classifications of areas, fields, and disciplines of science, can be distinguished from specific breakdowns, which are used exclusively to distinguish sub-disciplines in management sciences;
- openness to adding new sub-disciplines. In this case, open classifications, which assume the possibility of including additional sub-disciplines by the user, can be distinguished from closed classifications, which do not provide this possibility.

Based on a review of the literature and electronic sources, classifications in which specific sub-disciplines of management sciences are proposed include:

- the proposals of Sudoł, inspired by the work of the Committee of Organisation and Management Sciences of the Polish Academy of Sciences. In 2007, Sudoł (p. 43) distinguished four sub-disciplines of management sciences: (1) general theories of management, administration, and command, (2) management of economic organisations, (3) engineering management (production technology and processes), and (4) public management. He modified his proposal in 2014 by identifying three general specialisations: (1) theoretical foundations of management, (2) management in commercial organisations, and (3) management in public organisations. He further noted that as the management sciences develop, it will be helpful to distinguish more broadly ten specific sub-disciplines, including strategic management, human resources management, marketing, and quality management, and others (Sudoł, 2014, p. 31);
- the proposals of the Committee of Organisation and Management Sciences of the Polish Academy of Sciences (OM PAS). The first (version 1.0) was developed in 2014. It distinguished 21 sub-disciplines of management sciences based on a hierarchical arrangement of four levels: empirical nature, subject criterion, management level, and specific research specialisations (Cyfert et al., 2014). This proposal was subsequently modified in 2019 (version 2.0), considering the adaptation of sub-disciplines to systemic changes, the development of management theory and practice, and the strive to ensure the integrity of the entire discipline by integrating and eliminating existing sub-disciplines and organising their content. As a result, the number of specialisations was reduced to 18, each time justifying the changes and explaining them in detail (Belz et al., 2019);
- the proposal of the Committee of Economic Sciences of the Polish Academy of Sciences (Gorynia, 2013). It distinguishes six sub-disciplines in management sciences to determine the nature and distinction of this discipline within the field of economic sciences;
- the classification of sciences within the framework of panels of the National Science Centre (NCN Panels), Poland, which was developed for the qualification and evaluation process of research projects. It distinguishes three general panels: (1) HS — humanities, social sciences, and arts, (2) ST — science and technology, and (3) NZ — life sciences, followed by specific panels linked to scientific disciplines and particular research specialisations. Panel HS4 is interesting from the point of view of the management sciences as it includes Individuals, Institutions, and Markets, containing a classification of 15 sub-disciplines specific to economics, finance, management, demography, socio-economic geography, and urban planning. They include such sub-disciplines of management sciences as resources and sustainable development; corporate finance, accounting; consumption and consumer behaviour, marketing; strategic management, concepts and methods of management, logistics; human resources management, employment and wages, as well as public administration, among others. The classification is open, as other related topics can be reported in panel HS4_16;
- the 6-digit UNESCO nomenclature for fields of science and technology (1988), which distinguishes 24 various fields of science, including economic sciences (code 53), which are divided into 13 disciplines and 90 sub-disciplines. The specialisations of management sciences are primarily located in the discipline of "organisation and management of enterprises" (code 5311), where ten sub-disciplines have been distinguished along with the possibility of including additional proposals. However, individual sub-disciplines characteristic of management sciences are also present within other disciplines of economic sciences, e.g., technological innovation within "economics of technological change"; consumer behaviour within "general economics"; public enterprises within "industrial organisa-

tion and public policy", or international business within "international economics". As a result, clear identification of sub-disciplines of management sciences is difficult, and for further consideration, the authors adopted 84 sub-disciplines of economic sciences (excluding six specialisations within the disciplines of "domestic fiscal policy and public finance" and "economic systems");

- China's current classification by the Academic Degrees Committee of the State Council (ADCSC Classification, 2018), which distinguishes five sub-disciplines within management sciences: (1) management science and engineering, (2) business management, (3) agriculture and forestry management, (4) public management and (5) library intelligence and archives management. Its primary purpose is to define specialisations within the framework of academic degrees and professional titles conferred in higher education institutions;
- the code-based classification system of the Journal of Economic Literature (JEL Classification System..., 2022), developed by the American Economic Association as a standard method of classifying scholarly literature in the field of economics. This system is used to classify scientific papers, dissertations, books, book reviews, and working papers in economic literature. The system has undergone numerous changes over the years, and its current version includes three classification levels containing 20 categories at level 1, 122 two-digit codes at level 2, and 857 detailed three-digit codes at level 3 (Heikkilä, 2022). Because of the high complexity of the classification, the sub-disciplines of management sciences are placed in many different categories, with key ones being in the following categories: L — industrial organisation; M — business administration and business economics • marketing • accounting • personnel economics; O — economic development, innovation, technological change, and growth. The classification is open, as it is possible to include other research specialisations in each category;
- the Fields of Research (FoR) classification under the Australian and New Zealand Standard Research Classification ANZSRC (2020), developed for use in the measurement and analysis of research and development (R&D) statistics. It includes a total of 23 science divisions, including division No. 35: commerce, management, tourism, and services. Within its framework, nine groups of scientific issues were identified. The sub-disciplines of management sciences are located in eight of them, excluding group No. 3508: tourism. A total of 75 sub-disciplines are distinguished here, along with the possibility of including additional proposals;
- classification of the EURAM Strategic Interest Groups (2009), adopted within the European Academy of Management. It features an internal division of management sciences into 13 sub-disciplines including, but not limited to, business for society; corporate governance; entrepreneurship; gender, race, and diversity in organisations; managing sports; project organising; public and nonprofit management, as well as strategic management;
- the Italian ANVUR classification (2015) used by the National Agency for the Evaluation of the University and Research Systems (Agenzia Nazionale di Valutazione del Sistema Universitario e della Ricerca). Its internationalised version prepared by the Consiglio Universitario Nazionale identifies six sub-disciplines of management sciences within the macro-sector No. 13/B: business administration and management, although from a substantive point of view, it is debatable to include among them the sub-discipline SECS-P/13 — commodity sciences;
- the EIASM classification of domains of interest within the framework of the European Institute for Advanced Studies in Management. It is an internal division of economic sciences (including management sciences) into 112 sub-disciplines designated at two levels, including 18 at level 1 and 94 at level 2. The classification is open with the possibility of including additional proposals;
- the classification of the European Group for Organisational Studies (EGOS classification). The organisation operates through dynamically functioning working units, the so-called Standing Working Groups (SWGs), carrying out research in a specific area. For the years 2021–2023, 15 SWGs have been designated, including organisation and time; organising in and through civil society: perspectives, issues, challenges; social evaluations in organisation studies; organisation(al) networks: between structure and process; organisational paradox: engaging plurality, tensions and contradictions; organising desirable futures: sustainable transformation, impactful scholarship and grand challenges; digital technology, media and organisation; institu-

Tab. 1. Divisions and Interest Groups of the Academy of Management

CAR Careers 897 Members	**CM** Conflict Management 654 Members	**CMS** Critical Management Studies 691 Members	**CTO** Communication, Digital Technology, and Organisation 1063 Members	**DEI** Diversity, Equity, and Inclusion 1911 Members	**ENT** Entrepreneurship 3502 Members
HCM Health Care Management 736 Members	**HR** Human Resources 3058 Members	**IM** International Management 1840 Members	**MC** Management Consulting 877 Members	**MED** Management Education and Development 1445 Members	**MH** Management History 377 Members
MSR Management, Spirituality, and Religion 576 Members	**MOC** Managerial and Organisational Cognition 1272 Members	**OSCM** Operations and Supply Chain Management 522 Members	**OMT** Organisation and Management Theory 3897 Members	**ODC** Organisation Development and Change 1579 Members	**OB** Organisational Behaviour 5711 Members
NEU Organisational Neuroscience 389 Members	**ONE** Organisations and the Natural Environment 858 Members	**PNP** Public and Nonprofit 685 Members	**RM** Research Methods 2320 Members	**SIM** Social Issues in Management 1914 Members	**STR** Strategic Management 5197 Members
SAP Strategising Activities and Practices 620 Members	**TIM** Technology and Innovation Management 3203 Members				

Micro cluster	Macro cluster	Meso cluster

Source: elaborated by the author based on https://aom.org/network/divisions-interest-groups-(digs), 06.09.2023.

tions, innovation, impact: how institutional theory matters; as well as organising in and for extreme contexts;

- The Divisions and Interest Groups of the Academy of Management (DIG AoM) classification encompasses 26 specialisations integrating AoM members within individual teams. These areas are distinguished within specific clusters: (1) the micro cluster, which focuses on individual people; (2) the macro-cluster, focused on industries, markets, and professions; and (3) the meso cluster, which focuses on social structures and processes between micro and macro domains. Each DIG is characterised in detail within the so-called domain statements expressing the specificity of each research sub-discipline. This classification is closed, but changes do occur within it, particularly in the names of DIGs, which are related to the development of management sciences. Table 1 provides its current version with the number of members assigned to each DIG.
- the classification proposed by the Chartered Association of Business Schools (UK) within the framework of the Academic Journal Guide 2021: Methodology (AJG 2021). Its goal is to support researchers in making informed and rational decisions when selecting journals in which they would like to publish research conducted in the domain of management sciences. The AJG 2021 list includes 22 subject areas dominated by sub-disciplines directly related to management sciences. However, there are also specialisations related to other scientific disciplines, such as psychology (general and organisational), regional studies, planning, and environment;
- the classification of Scopus-Elsevier (Scopus Sources), developed for the thematic classification of scientific journals. It lists 27 subject areas divided into specific research specialisations. From the point of view of management sciences, of particular importance is a set of 11 sub-disciplines in the area of Business, Management and Accounting, which include, among other things, business and international management, industrial relations, management of technology and innovation, marketing, or strategy and management;

- the classification of the Web of Science Journal Citation Reports (WoS JCR), used to qualify scientific journals into specific thematic groups. It includes 254 categories divided into 21 thematic groups. A catalogue of sub-disciplines characteristic of management sciences can be found in the "Economics & Business" group. It includes a list of 21 specialisations, with some relating to economics or other scientific disciplines (e.g., economics, demography, geography) and others being interdisciplinary in nature (e.g., area studies, ethnic studies, and urban studies).

The review of the literature and selected classifications presented above leads to the formulation of the research problem, which covers the identification and assessment criteria for the sub-division of management sciences sub-disciplines in national and international research practice. This research problem was operationalised into two research questions:

RQ 1: What sub-division criteria are used to distinguish sub-disciplines of management sciences in classifications of research specialisations? This question covers the analysis within a positive approach and identifies the key criteria of management sciences' sub-discipline classifications.

RQ 2: To what extent are the criteria used to divide sub-disciplines in line with the expectations of the management sciences community? The second question refers to community evaluation of applying selected criteria in management sciences' sub-disciplines classifications. Since its goal is to understand the alignment of classification practice with researchers' preferences, it includes the analysis within a normative approach.

Such a defined research problem is essential to understanding the evolution and creating new opportunities for further development of management sciences because scientific sub-disciplines play an essential role in determining the scope and building the identity of management sciences (Koźmiński, 2007; Sudoł, 2014, p. 29). They also significantly determine the development prospects of this scientific discipline by strongly influencing the substantive scope, methodological rigour, and level of its internal integration and organisation (Kozłowski & Matejun, 2018). The research problem defined above also provides a better description and understanding of multi-paradigmatic, multi-disciplinary, and poly-methodological perspectives, which should be applied to management sciences, according to Sułkowski (2014).

2. Research methodology

Aiming to achieve the paper's purpose and answer the research questions, the authors conducted empirical research using triangulation (Easterby-Smith et al., 2021, pp. 253–254) of (1) document study (Lisiński & Szarucki, 2020, pp. 122–123) and (2) expert opinion survey (Bougie & Sekaran, 2020, pp. 126–127). The research was conducted during the Polish author's research fellowship at Chongqing Jiaotong University, China. Therefore, the origin of experts involved in the study was intentional and resulted from scientific cooperation between authors. This approach allowed for including various national and international classifications of management science sub-disciplines in the research process and assessing whether the geographical context affects the diversity of expert opinions about criteria for classifying sub-disciplines of management sciences in research practice.

The document study employed the context and content analysis technique, and the sources of information were the 16 classifications of management sciences' sub-disciplines characterised in the theoretical part of the paper. It aimed to identify the key criteria of management sciences sub-discipline classifications. The research tool was a control list consisting of 13 criteria discussed in the theoretical part of the paper. The research procedure was divided into three stages:

- stage 1 consisted of identifying and evaluating the sub-division criteria used in the 16 described classifications independently by each author of the paper. It was established that it is sufficient to identify at least one sub-discipline distinguished based on a particular criterion to consider that this criterion was used in a given classification;
- stage 2 involved consultation between the authors and subsequent formulation of an agreed list of criteria used in the sub-discipline classifications under consideration;
- stage 3 aimed to increase the validity and reliability of findings through substantive consultation with two independent experts representing the management sciences community. The final list of criteria used in the sub-discipline classifications under consideration was adopted on this basis.

Out of the analysed classifications, seven were general in nature. At the same time, nine were devel-

Tab. 2. Characteristics of the analysed sub-discipline classifications

Classification	Country / Area	Main aim(s)	Scope	Levels of classification*	Number of sub-disciplines	Boundaries
S. Sudoł 2014	Poland	• separation and integration of the scientific community • development of research teams • identification of research interests	specific	1	10	close
OM PAS 2.0	Poland	• separation and integration of the scientific community • development of research teams • identification of research interests	specific	4	18	close
Econ PAS	Poland	• separation of the scientific community	specific	1	6	close
NCN	Poland	• distribution of funds for scientific research	general	3	15**	open
UNESCO	International	• implementation of statistical obligations	general	3	84**	open
ADCSC 2018	China	• conferment of specialisations within the framework of academic degrees	general	2	5	close
JEL	USA	• classification of scientific publications in economic sciences	specific	3	857**	open
ANZSRC 2020	Australia and New Zealand	• implementation of statistical obligations	general	3	75	open
EURAM	Europe	• identification of research interests • integration of the scientific community • organisation of a scientific conference	specific	1	13	close
ANVUR	Italy	• evaluation of scientific and teaching activities	general	3	6**	close
EIASM	Europe	• identification of research interests	specific	2	112**	open
EGOS 21–23	Europe	• integration of the scientific community • development of research teams	specific	1	15	open
DIG AoM	USA	• identification of research interests • integration of the scientific community	specific	2	26	close
AJG 2021	UK	• support in the selection of scientific journals	specific	1	22	close
Scopus	International	• classification of scientific journals	general	2	11	close
WoS JCR	International	• classification of scientific journals	general	2	21**	close

* In the case of general classifications, the number of levels of the entire classification is given.

** Including specialisations from other scientific disciplines, mainly economics.

oped only to distinguish sub-disciplines in management sciences (or in economic sciences in the case of the JEL classification). They contain research specialisations from min=5 to max=857. However, in some classifications, it was impossible to clearly distinguish research specialisations exclusively in management sciences. Hence, the given number includes sub-disciplines from other scientific disciplines, mainly economics. The hierarchical arrangement of the analysed classifications ranges from min=1 to max=4 levels of classification, and most of them (n=10) are closed and do not provide the possibility of adding other/new sub-disciplines to the proposed list. Detailed characteristics of the analysed classifications are shown in Table 2.

The second part of the research was the expert opinion survey, which included representatives of the management sciences community from Poland and China. It aimed for community evaluation of the selected criteria application in management sciences' sub-discipline classifications. The sampling of respondents was intentional and purposive. Invitations were sent to the School of Economics and Management of Chongqing Jiaotong University staff, representatives of the Committee of Organisation and Management Sciences of the Polish Academy of Sciences, and scientists who expressed interest in the survey.

Communication with respondents was conducted via e-mail. A total of 80 e-mail invitations were sent to participate in the survey. A return of 33 questionnaires was received (a return rate of 41 %), but two were incomplete and were not included in the final sample. The final sample, therefore, included 31 responses, out of which 20 were from representatives of the management sciences community from Poland and 11 from China.

Therefore, the sample size meets the methodological requirements for expert research, requiring the size of the expert panel to range from about ten to about 50 participants (Shelton et al., 2018; Wuni & Shen, 2023). In addition, factors affecting the optimal expert sample size were considered, such as the homogeneity of the sample (researchers representing the same scientific discipline) and the study's exploratory nature. As Garson (2014) recommended, the sample size can be smaller in these cases.

The research technique was an e-mail survey, and the research tool was the authors' own expert questionnaire prepared in an MS Word document consisting of 12 questions and particulars. The experts received a certificate acknowledging their participation in the survey.

The group of expert respondents was dominated by senior academic staff members: full professors (seven) and associate professors (14). In addition, the survey included assistant professors (seven), two lecturers, and one assistant. The respondents represented various research interests, including, but not limited to, marketing, logistics, finance management, human resources management, entrepreneurship, strategic management, innovativeness, and public management. The period of their scientific activity was most often over 20 years (ten experts), as well as 6–10 and 11–15 years (seven experts for each range).

3. Research results

3.1. Sub-division criteria in investigated classifications

The first part of the research involved identifying and evaluating the sub-division criteria used to distinguish sub-disciplines of management sciences in the 16 described classifications of research specialisations. As a result of the document research procedure, the final list of criteria used in the sub-discipline classifications under consideration was adopted, as presented in Table 3.

The results indicate that the most widely used criteria for dividing sub-disciplines (more than 80 % of the classifications analysed) are:

- resources, which are primarily due to the common distinction of the "human resources management" sub-discipline in the classifications analysed. Other sub-disciplines distinguished under this criterion include, e.g., "management of non-material resources" (Sudoł, 2014), "resources and sustainable development" (NCN), "resource management" (Econ PAS), and "manpower management" (UNESCO). The use of this criterion was not identified only in the ADCSC 2018 classification;
- areas of activity, referring substantively to the functions of enterprises and allowing to distinguish a broad and diverse range of sub-disciplines, including, but not limited to, "production management", "logistics management", "marketing management", and "financial management". The application of this criterion was not identified only for the Econ PAS and EGOS 21–23 classifications;
- concepts and methods of management, expressing the differentiation of sub-disciplines according to specific conceptual approaches, methods, and tools of management. In this case, the criterion was used to distinguish both general sub-disciplines, e.g., "methods and instruments of management" (Econ PAS), "concepts and methods of management" (NCN), as well as specific ones, including but not limited to "project management", "innovation management" (ANZSRC 2020), "financial risk and risk management" (JEL), "organisational change", "knowledge management" (EISAM) and "conflict management" (DIG AoM). The use of this criterion was not

Tab. 3. Distinction criteria used in the considered classifications of management sciences' sub-disciplines

Criteria	Scope of using	Sudoł 2014	OM PAS 2.0	Econ PAS	NCN	UNESCO	ADCSC 2018	JEL	ANZSRC 2020	EURAM	ANVUR	EIASM	EGOS 21–23	DIG AoM	AJG 2021	Scopus	WoS JCR
Areas of activity	14	+	+		+	+	+	+	+	+	+	+		+	+	+	+
Concepts and methods of management	14	+	+	+	+	+		+	+	+	+	+	+	+	+	+	
Empirical engagement	9	+	+			+		+	+	+		+	+	+			
Functions of management	5					+			+			+	+		+		
Geographic range	9				+	+		+	+	+		+		+	+	+	
Level of aggregation	11		+		+	+		+	+			+	+	+	+	+	+
Management level	12	+	+	+	+	+			+	+		+		+	+	+	+
Processes	7	+	+					+	+			+	+	+			
Prospects for development	1												+				
Reality	2												+	+			
Resources	15	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+
Time	7					+		+	+			+	+	+	+		
Type of organisations	14	+	+			+	+	+	+	+	+	+	+	+	+	+	+
No. of criteria used in specific classification		**7**	**8**	**3**	**6**	**10**	**2**	**9**	**11**	**7**	**4**	**11**	**10**	**11**	**9**	**7**	**5**

+ means that the criterion was indicated in a specific sub-discipline classification

identified only for the ADCSC 2018 and WoS JCR classifications;

- type of organisations, which primarily distinguished "public management" or "management of public organisations" (Sudoł 2014, OM PAS 2.0, UNESCO, ADCSC 2018, or ANZSRC 2020). Other types of organisations include "small business management" (ANZSRC 2020, EIASM), "health care management" (DIG AoM, AJG 2021), "sports and leisure management" (ANZSRC 2020) or "financial markets and institutions" (ANVUR). Differentiation by type of organisation is particularly extensive in the UNESCO classification, which distinguishes ten sub-disciplines within area 5311: "Organisation and management of enterprises", as well as 13 sub-disciplines within area 5312: "Sectorial economics" relating to enterprises in such industries as agriculture, forestry, fishing, energy, mining, research and development, trade and commerce, or transport and communications. The use of this criterion was not identified only for the Econ PAS and NCN classifications.

It should be highlighted that clearly distinguishing sub-disciplines can be difficult based on the first three criteria. This is because the various sub-disciplines can intersect and overlap within each criterion. An example is "human resource management", which can be considered both in terms of resources, as an enterprise function, and — in addition — as a formalised management concept (method). This problem is highlighted by Cyfert et al. (2014), who proposed the introduction of a three-dimensional matrix of sub-disciplines in strategic, operational, and functional terms, further expanded with the fourth dimension of organisation type. According to the authors, such a solution makes it possible to imaginatively create new analytical cross-sections and prospects for developing sub-disciplines, covering the broad context of management holistically and looking for potential problems to analyse in scientific papers and projects.

Other commonly used criteria for dividing sub-disciplines (50 % – 80 % of the classifications analysed) include:

- management level, the prevalence of which (75 %) is due to the frequent distinction of the "strategic management" sub-discipline, as well as emphasising the strategic level of management in other sub-disciplines, e.g., "marketing management (incl. strategy and customer relations)" (ANZSRC 2020), "accounting & strategy" or "strategic human resource management" (EIASM). Furthermore, the analysed classifications distinguished the operational level of management (ANZSRC 2020, EIASM, DIG AoM, and sfdAJG 2021). However, the tactical level of management was not identified as a criterion for classifying sub-disciplines;
- aggregation level, which makes a distinction between micro-level sub-disciplines, relating, among other things, to "consumer behaviours" (UNESCO), "employee relations" (ANZSRC 2020), or "managerial cognition" (DIG AoM, EIASM); meso-level sub-disciplines, relating to entire organisations (OM PAS 2.0, NCN), as well as macro-level sub-disciplines, considering primarily "industrial relations" (EIASM, Scopus, WoS JCR). This criterion was particularly important in the EGOS 21–23 classification, where the names of sub-disciplines emphasised "occupations and professions" (micro level), "organisational, institutional implications" (meso level), as well as "organisational networks" (macro level), among other things;
- empirical engagement, which involves the distinction between theoretical and practical specialisations in management sciences. This criterion is strongly emphasised in Polish classifications Sudoł 2014 (as "theoretical foundations of management") and OM PAS 2.0. ("organisation and management theory"). Similarly, theoretical sub-disciplines are distinguished in many theoretical streams of the UNESCO classification, in the ANZSRC 2020 classification ("marketing theory" or "organisation and management theory"), in EIASM (as "organisation theory"), in EGOS 21–23 ("SWG 12: Institutions, innovation, impact: How institutional theory matters"), as well as in DIG AoM (as "organisation and management theory"). The practical stream, on the other hand, was emphasised in the JEL ("firm behaviour: empirical analysis") and EURAM classification (as "research methods and research practice");
- geographic range primarily associated with the distinction of specialisations emphasising the international scope of the considerations carried out. Examples include such sub-disciplines as "international business" (UNESCO, JEL, ANZSRC 2020, EIASM), "international management" (EURAM and DIG AoM), "international business and area studies" (AJG 2021) as well as "business and international management" (Scopus).

Meanwhile, the following criteria for distinguishing management sciences' sub-disciplines were used to the most minor extent (less than 50 % of the classifications analysed):

- time, which mainly emphasised sub-disciplines related to the past of management sciences, e.g., "business and labour history" (ANZSRC 2020), "micro-business history" (JEL), "accounting history" (EIASM), "management history" (DIG AoM) or "business and economic history" (AJG 2021). Challenges related to the development of research specialisations in management sciences over time were also identified in "SWG 01: Organisation and time" under the EGOS 21–23 classification;
- processes, which were directly emphasised primarily in Polish classifications by Sudoł (2014) as "management of production technology and processes" and OM PAS 2.0 as "process and project management", as well as in the EGOS 21–23 classification as "SWG 07: Organisation(al) networks: Between structure and process". Because of the close substantive relationship between the concepts of process management and supply chain management (Mc Loughlin et al., 2023), specialisations distinguished based on this criterion also included "supply chains" (ANZSRC 2020), "supply chain management" (EIASM) and "operations and supply chain management" (DIG AoM). The JEL classification, on the other hand, distinguishes "processes of innovation and invention" as a research specialisation;
- functions of management, for which sub-disciplines have been identified that relate to both planning, e.g., "organisational planning and management" (ANZSRC 2020), organising, e.g., "organisation of production" (UNESCO),

"organisational studies" (AJG 2021), leading, e.g., "leadership" (ANZSRC 2020), as well as controlling, e.g., "audit & control" (EIASM);

- reality, which emphasised the digital and virtual dimensions of research specialisations in management sciences. Only two sub-disciplines have been identified on this basis: "SWG 11: Digital technology, media and organisation" under the EGOS 21–23 classification, as well as "communication, digital technology, and organisation" under the DIG AoM classification;
- prospects for development, for which only one research specialisation has been identified, "SWG 10: Organising desirable futures: sustainable transformation, impactful scholarship & grand challenges", under the EGOS 21–23 classification.

In addition to the wide range of criteria used to distinguish sub-disciplines, the dynamic nature of the analysed classifications is also noteworthy. Indeed, a significant part of them has been modified in recent years to adapt them to current and prospective development directions in management sciences. Examples of these changes include the update of Polish OM PAS 2.0 classification due to system changes in 2019, new versions of the ADCSC 2018, ANZSRC 2020, and AJG 2021 classifications, the introduction of an additional level of micro-, meso- and macro-clusters in the DIG AoM classification, as well as dynamic thematic changes in the EGOS 21–23 classification.

3.2. Sub-division criteria in expert review

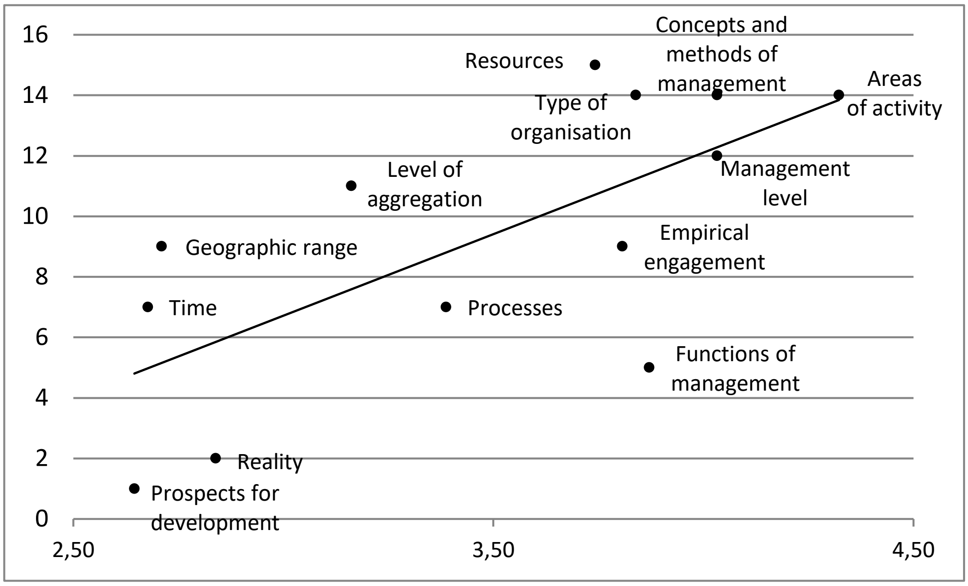
In the second part of the research, respondents from Poland and China were asked to evaluate the usefulness of each criterion for distinguishing management sciences' sub-disciplines in research practice. Experts rated the usefulness of each criterion on an ordinal Likert scale ranging from 1 (very low usefulness) to 5 (very high usefulness). In addition, they had the option to include additional criteria, yet it was not used. A comparative analysis of the average indications of Chinese and Polish respondents was also conducted. Because the assumptions about the normality of the distributions of the individual variables were not met, a nonparametric Mann–Whitney U test was used for this purpose. The results obtained (overall and from each country) are shown in Table 4.

Respondents found the following criteria to be the most valuable (average score above 4): (1) areas of activity, referring substantively to the division according to the function of an enterprise; (2) management level, related to distinguishing the strategic, tactical and operational levels of management, and (3) con-

Tab. 4. Respondents' evaluation of the usefulness of the criteria for distinguishing management sciences sub-disciplines

Criteria	Mean of responses from respondents			U Mann–Whitney	Mean rank	
	in total	from China	from Poland		from China	from Poland
Areas of activity	4.32	4.64	4.15	72.5	19.41	14.13
Concepts and methods of management	4.03	4.18	3.95	100.5	16.86	15.53
Empirical engagement	3.81	4.36	3.50	60*	20.55	13.50
Functions of management	3.87	4.45	3.55	59*	20.64	13.45
Geographic range	2.71	3.82	2.10	15.5**	24.59	11.28
Level of aggregation	3.16	3.91	2.75	48.5**	21.59	12.93
Management level	4.03	4.18	3.95	96.5	17.23	15.33
Processes	3.39	3.55	3.30	93	17.55	15.15
Prospects for development	2.65	3.27	2.30	57*	20.82	13.35
Reality	2.84	3.09	2.70	91	17.73	15.05
Resources	3.74	3.64	3.80	95.5	14.68	16.73
Time	2.68	3.45	2.25	54.5*	21.05	13.23
Type of organisation	3.84	4.09	3.70	87.5	18.05	14.88

*p < 0.05; **p < 0.01.



X-axis: Respondents' evaluation of the usefulness of the criteria for distinguishing management sciences' sub-disciplines
Y-axis: The scope of using a specific criterion in classifications of management sciences sub-disciplines under consideration

Fig. 1. Correlation of the extent of use of each criterion in the classifications analysed with the evaluation of experts

cepts and methods of management, expressing the conceptual richness of management sciences. The second group comprises criteria with above-average usefulness (average score above 3, up to 4), which include: (4) functions of management, (5) type of organisation, (6) empirical engagement, (7) resources, (8) processes, and (9) level of aggregation. They provide an opportunity to deepen and diversify the classifications by introducing several specific research specialisations. The last group consists of criteria with below-average usefulness, which include (10) reality, (11) geographic range, (12) time, and (13) prospects for development. The low ratings indicate the respondents' limited recommendation to use these criteria in research practice.

The results show that Chinese respondents rated the usefulness of most criteria slightly higher. However, there were no statistically significant differences in the evaluation by Chinese and Polish respondents for the group of the most valuable criteria. Such differences were identified for six criteria in the groups with above-average and below-average usefulness: empirical engagement, functions of management, level of aggregation, geographic range, prospects for development, and time. This means the respondents generally agreed when evaluating the principles for creating a classification of sub-disciplines in management sciences.

The final part of the research evaluated the extent to which the criteria used to divide sub-disciplines align with the expectations of the management sciences community representatives from Poland and China. This was achieved using the correlation of the extent of use of each criterion in the classifications analysed with the respondents' evaluation, as shown (along with the trend line) in Fig. 1.

The results indicate that, in general, the extent of application of each criterion in the compared classifications is mainly consistent with the survey participants' evaluation of its usefulness, r_{xy} (n=13) = 0.69. Based on the detailed results, it can further be concluded that the extent to which each criterion is applied in research practice is slightly more in line with the expectations of representatives of the management sciences community from Poland, r_{xy} (n=13) = 0.67, than from China, r_{xy} (n=13) = 0.58.

4. Discussion of the results

The research allows for answering the initial research questions:

RQ 1: What sub-division criteria are used to distinguish sub-disciplines of management sciences in classifications of research specialisations?

A wide variety of criteria can be used to distinguish research specialisations in management sciences. The results showed that the following criteria play a leading role in the analysed classifications: (1) resources, referring to the resource-based view in management (Barney et al., 2021); (2) areas of activity, substantively related to specific functions of enterprises (Misiński, 2021, p. 43), (3) concepts and methods of management, expressing the diversity of conceptual approaches, methods, and tools of management (Szymańska, 2021), emphasised, e.g., by the "management theory jungle" metaphor (Brunsson, 2021), and (4) types of organisations, highlighting subject diversity in research conducted within management sciences (Farah et al., 2020).

The second group consists of criteria that allow additional, specific types of research specialisations to be introduced into the analysed classifications. Using the management level criterion, mainly the strategic and operational context of managerial activity was distinguished (Berisha-Namani, 2010); on the other hand, the level of aggregation criterion allowed for distinguishing sub-disciplines relating to individual people, such as employees, consumers, managers (micro level), whole organisations (meso level), as well as inter-organisational, network or industry relationships and relations (macro level), which fits in with the concept of three levels (scales) in social analyses (Serpa & Ferreira, 2019), as well as the basic assumptions of analyses within the framework of institutional theory (Van Wijk et al., 2019). The empirical engagement criterion mainly emphasised the theorising and theoretical nature of the considerations underpinning the development of management sciences and their respective sub-disciplines (Brunsson, 2021), while the geographic range criterion mainly highlighted the international scope of the considerations (O'Higgins et al., 2021). Meanwhile, criteria for distinguishing sub-disciplines used to the least extent include time, processes, management functions, reality, and prospects for development.

Interestingly, the vast majority of key identified criteria are specific and characteristic for management sciences only (e.g., resources, areas of activity, type of organisations, management level, and aggregation level). This indicates the important role of the sub-disciplines distinguished on their basis in building a strong and forward-looking identity for management science. After a suitable adaptation, some criteria (concepts and methods, geographic range, and the level of aggregation) can be successfully used to classify research specialities within other scientific disciplines. However, universal criteria (empirical engagement, prospects for development, and time) that can be used successfully to distinguish sub-disciplines in other knowledge domains were identified to a much lesser extent.

RQ 2: To what extent are the criteria used to divide sub-disciplines in line with the expectations of the management sciences community?

The results indicate that the criteria used to divide sub-disciplines are well in line with the expectations of the representatives of the management sciences community who participated in the survey. This is confirmed by the high convergence of the experts' evaluations of the practical usefulness of each criterion with the extent of its use in the analysed classifications. Based on the comparison of the results with the trend line, it can also be concluded that in the case of five criteria, i.e., (1) prospects for development, (2) reality, (3) processes, (4) empirical engagement, and (5) functions of management, experts expect them to be used for distinguishing research specialisations to a slightly greater extent than is apparent from the current practice of the analysed classifications.

The considerations are a part of the current and prospective discussion of the past and future and promising research specialisations within management sciences (Wang, 2022; Bylund & Packard, 2022; Redgrave et al., 2022). The results also play an essential role in the process of emergence, constitution, and development of new sub-disciplines. As examples of such trends, one can point to calls for the separation of such research specialisations as arts management (Evrard & Colbert, 2000), sports management (van der Roest et al., 2015), lean ergonomics (Brunner et al., 2022), or even logistics 4.0 (Szymańska et al., 2017).

Changes in this area are evolutionary rather than revolutionary, always involving in-depth substantive debate and challenges to existing paradigms (Boyd et al., 2005, p. 240). However, the results confirm that these changes occur and influence the development of management sciences, as evidenced by the dynamic nature of the analysed sub-discipline classifications. This problem is considered particularly by Sudoł (2019), who encouraged reasonable restraint in introducing new research specialisations and limited their excessive number. According to him, excess research specialisations could lead to the disintegration of management sciences and its degradation as a scientific discipline. It would negatively affect the quality of student education. This should be countered by establishing research specialisations as part of the sub-disciplines, encouraging the lively cooperation of research workers from individual disciplines and research specialisations, and not neglecting theoretical studies in management.

The results are also highly useful in the process of reviewing and/or placing particular research issues or problems in specific sub-disciplines of management sciences. This approach represents a vital stream of theoretical and empirical considerations, as exemplified by the research on lodging-related organisations and the lodging industry, which analysed the issue under consideration in relation to 15 sub-disciplines of management sciences (Okumus et al., 2018), as well as the work by Caruana et al. (2021), who analysed the phenomenon of modern slavery in the context of six sub-disciplines. As for other instances, Stefanidis et al. (2022) considered the 25-year development of management research on poverty from the perspective of nine research specialisations, while Dey et al. (2020) evaluated critical research and entrepreneurship in terms of five sub-disciplines of management sciences based on 151 scientific papers.

Thus, the conclusions of the discussion indicate the importance of considering the refinement of sub-discipline classifications in the development of management sciences. However, when considering the conclusions of the empirical analyses, it is also important to consider the limitations of the conducted research (Geletkanycz & Tepper, 2012). First and foremost, these include the subject scope, which was limited to 16 classifications of management sciences' sub-disciplines and a sample of 31 representatives of the scientific community from Poland and China. Efforts were made to limit the potentially negative impact of these factors by selecting sub-discipline classifications originating from different countries and developed for various practical applications (including the evaluation of scientific activity, distribution of funds for research work, implementation of statistical obligations, or integration of the scientific community). In the case of the expert survey, efforts were made to involve key representatives of the management sciences community, including, among other things, representatives of the Committee of Organisation and Management Sciences of the Polish Academy of Sciences. Another limitation may be the subjectivity of assessments in the document and expert research. In the case of the document study, an effort was made to minimise this adverse impact by using a 3-stage research procedure that included inter-researcher agreements and external consultations with independent experts representing the scientific community. On the other hand, the expert survey used a standardised survey questionnaire in English, which positively reduced the potentially adverse impact of the linguistic interpretation of the questions.

Conclusions

Sub-disciplines are crucial in building the management sciences community's identity, organisation, and development. They are distinguished based on specific criteria, the selection and application of which determine the practical usefulness of the created classifications.

The theoretical considerations and the research results indicate that national and international classifications of management sciences' sub-disciplines are created based on various criteria. The following criteria play a crucial role: (1) resources, (2) areas of activity, (3) concepts and methods of management, and (4) types of organisations. They were used in most (more than 80 %) studied classifications, laying the conceptual and logical foundations for their creation and further development.

An important role is also played by supplementary criteria, which include (5) management level, (6) aggregation level, (7) empirical engagement, and (8) the geographic range. They enable deepening the classification by adding more specific research specialisations. In contrast, the following criteria were used to a lesser extent (less than 50 %) in the classifications studied: (9) time, (10) processes, (11) functions of management, (12) reality, and (13) prospects for development. The results showed that the surveyed experts rated most of their usefulness slightly higher than initially appeared from the current practice of the analysed classifications. In general, however, the extent of the use of the analysed criteria was well in line with the expectations of the representatives of the management sciences community participating in the survey.

Therefore, the scope of analysis to solve the set research problem contributed to both approaches to considering sub-disciplines of management science: positive (how it is) and normative approach (how it should be). Explorations in the field of the positive approach made it possible to identify key criteria for distinguishing sub-disciplines in national and international classifications of management sciences.

Analyses within the normative approach, on the other hand, allowed for assessing the alignment of the preferences of the scientific community representatives with the extent to which specific criteria are used for classifying the specialities of the management sciences.

The dynamic nature of the development of the discipline and sub-disciplines of management sciences indicates the need for continued research on the purposes, principles of development, logic for distinguishing, and substantive scope of the classification of research specialisations. Potentially interesting and promising future research directions in the field of management sciences' classification include:

- creative discussions and creative sessions directed at identifying new criteria that can be used in classifications of management sciences' sub-disciplines,
- contextual analyses (e.g., by location, position in the scientific community) of perceptions of the particular criteria usefulness by representatives of the management science community,
- longitudinal studies to identify development trends in the area of new management sciences' sub-disciplines emergence and development,
- analyses aimed at challenges and prospects of defining the thematic scope of sub-disciplines and their impact on the development of management sciences in the long term.

Therefore, there should certainly be a discussion in the scientific community on improving and further developing the classifications of management sciences sub-disciplines in theory and research practice.

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Evaluating the current state of Digital Era Governance application in local government units in the Małopolska region

Angelika Wodecka-Hyjek
Rafał Kusa
Tomasz Kafel

ABSTRACT
The study aims to determine the implementation degree of Digital Era Governance (DEG) in selected local government units (LGU) of Małopolskie Voivodeship and to show differences in the effectiveness of digitalisation in LGUs depending on the level of local government, i.e., the county and the municipality. The study employs a model of digital maturity intended specifically for public administration. This model assesses six dimensions of digital maturity, namely, digitalisation-focused management, openness to stakeholders' (partners') needs, digital competencies of employees, digitalisation of processes, digital technologies, and e-innovativeness. The study results indicate that the examined local government units in the Małopolska region suffer from a low level of digital maturity. In particular, the results show that the implementation of digital technologies and the digital competencies of staff are the most developed dimensions of digitalisation in the examined local government units. In turn, e-innovation and process digitalisation are the least developed areas and require further improvement. Additionally, digital maturity is lower at the municipal than county level. These findings confirm the thesis that New Public Management affects the development of local government and highlights the increasing role played by Digital Era Governance. In contrast to most studies on public administrations, this study focuses on the local government level. It employs the original model of digital maturity in the field of public administration. This study intends to contribute to the concept of Digital Era Governance by focusing on the digitalisation of LGUs.

KEY WORDS
digitalisation, local government unit, public sector, the Digital Era Governance concept

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Tomasz Kafel

Krakow University of Economics, Poland
ORCID 0000-0003-2931-1921
Corresponding author:
e-mail: kafelt@uek.krakow.pl

Angelika Wodecka-Hyjek

Krakow University of Economics, Poland
wodeckaa@uek.krakow.pl
ORCID 0000-0002-6930-4438

Rafał Kusa

AGH University of Krakow, Poland
ORCID 0000-0002-9819-897X
e-mail: rkusa@agh.edu.pl

Introduction

Over the past few decades, the digitalisation of public services has been the subject of extensive research. The basic objective of these analyses has been to demonstrate how digital technologies (service automation, data mining, machine learning) and modern tools and methods of communication and information transfer (e.g., social media, applications, podcasts, chat, etc.) are used to improve the quality and efficiency of services by shortening the time required for their implementation, increasing the

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existing range of services, and to enhance the transparency or smoothness of their provision (e.g., Layne & Lee, 2001; Norris & Reddick 2011; Matheus, Janssen, & Maheshwari, 2018). Increasing automation in these areas, combined with the use of information technology in the creation and distribution of public services, are central issues for New Public Management (NPM) (Hood, 1991) and Public Governance (PG). While in the case of NPM, the reference point is citizens as consumers, for PG, the focus is on citizens as stakeholders (Izdebski, 2007). The basic PG assumption is the inclusion of citizens in governance processes aiming to achieve public value and thus satisfy the needs of various stakeholder groups. One means of implementing the goals of NPM and PG is e-government (electronic administration), which assumes the use of information and communication technologies in bringing about organisational change and promoting new skills to improve the quality of public services and greater citizen involvement in and support for state policy (Grodzka, 2007). It is worth mentioning that in past years, some other perspectives on e-governance developed, like m-government (Burksiene et al., 2019).

The impulse for implementing digital solutions in the public sector (in the mid-1990s) came from the expansion of electronic commerce, as a result of which citizens now enjoy almost unlimited access to knowledge and an ever-wider range of online services and thus, nowadays, expect similar standards in terms of access to public information and public services (Śledziewska & Włoch, 2020). The COVID-19 pandemic, the financial upheaval of the first decade of the 21st century, the current energy crisis, inflation, an ageing population, migrations, and climate threats have given rise to new social problems and posed new challenges to the public administration. They have provided an incentive for redefining public policies and expanding the regulatory role of central and local government units. Based on the public administration theory and its functioning, these developments have highlighted the shortcomings and the strengths of the public management models applied to date. These challenges are addressed by the concept of the Neo-Weberian State, which endeavours to combine the most effective solutions applied in previous theories and concepts of public management. Another consequence of the changing situation has been the emergence of Digital Era Governance (DEG), which is a product of the digital revolution and its more advanced version, i.e., "Essentially Digital Governance" or the "Essentially Digital" Model of Governance (EDGE). The EDGE model places digital technologies at the centre of management, setting out the principles of public administration in the era of social media, cloud computing, robotisation, and big data. It also identifies organisational cultures that may promote EDGE practices (Dunleavy & Margetts, 2015). The key features of DEG and EDGE are reintegration (concerning the construction of public administration), customer orientation and digital change (including technological, social and cultural adjustments to digital change). Common to both concepts is a doubt about how the public administration has been operating so far and the pressure to open it up internally and externally towards simplification, automation of daily work and flexibility in delivering public services (Białożyt, 2017).

Dunleavy et al. (2006) point out that technology does not per se change public institutions but rather shapes how they function and their work practices. They consider the effects of technological change in a broader context, focusing on organisational, cultural and social change. This multifaceted approach makes it possible to track the consequences of digital transformation. This thesis is also supported by Meijer and Bekkers (2015), claiming that research on digital transformation effects should strive to understand how technology affects social constructs and government, consider, and understand social attitudes, the behaviours of individual participants, interests, values, positions and local and institutional connections. As a consequence, digital transformation should be understood from the perspective of an organisation as a whole, without losing sight of the fact that IT is not a means of supporting change per se but rather a means of processes, people, politics and in particular, leadership. The authors of this study have considered these factors by analysing the impact of digital maturity on local government units in the Małopolska region.

Assessing an organisation's digital maturity is an increasingly popular topic for researchers. As part of a systematic literature review on the digital transformation of business organisations, Jedynak et al. (2021) regarded the digital business model as an aggregate synonymous with the use of such digital technology tools as the Internet of Things, blockchain, machine learning, cloud computing, wireless communications, ICTs, Big Data, and Multi-sided platforms. In addition, they point out that employees and their skills, experiences, knowledge gaps, skill mismatches, engagement, and behavioural changes play a significant role in the digitalisation of an organisation. When estimating an organisation's level of maturity, the following three categories must be considered: people, processes, and preparedness.

A review of numerous studies on public sector digitalisation reveals the predominance of analyses conducted at the state (central) administration level (Miazga et al., 2022). So, the following research question has arisen: to what extent is digitalisation in local government units developed? This question is justified by the lack of any distinction between the local and central levels in research on digitalisation in public administration in the European Commission in Digital Economy or the Society Index (DESI) reports since 2014. The present study aims to determine the degree of implementation of Digital Era Governance (DEG) in selected local government units (LGU) in Małopolskie Voivodeship. To assess the level of digital maturity in these entities, the authors employed an original digital maturity model. Another aim of the article was to show differences in the effectiveness of digitalisation in LGUs depending on the local government level, i.e., the county and the municipality. This study intends to contribute to the Digital Era Governance concept by focusing on LGU digitalisation.

The remaining part of the article is as follows. The next part reviews the literature regarding the digitalisation of public administration in Poland and progress in the digitalisation of public services in Poland at the local government unit level. Then, the research methods and research results are described. Finally, the results are discussed with previous literature and conclusions are presented.

1. Literature review

1.1. Digitalisation of the public administration in Poland set against the background of other European Union countries

Digitalising public administration services is part of the EU's broader Digital Single Market Strategy (Communication from the Commission…, 2015). In the case of Poland, the framework for digitalisation in this area has also been defined in, e.g., the Strategy for Responsible Development of 2017 and the strategic document the Programme for the Integrated Informatisation of the State 2019–2022. The latter sets out several activities aimed at developing the public administration in Poland through modern digital technologies and fostering conditions that facilitate communication between citizens and the public administration using information resources and implementing measures designed to adapt digital solutions to its needs and make them accessible. The Strategy's main objective is to modernise the public administration and streamline the state's functioning with digital technology, which, in turn, is aimed at improving the quality of communication between citizens and other public administration stakeholders. As part of this main objective, several more specific objectives were defined, focusing on three areas of intervention: reorienting the public administration towards services intended for the needs of citizens, implementing horizontal tools that support public administration activities, and developing the digital competences of citizens, public administration employees and ICT specialists (Program Zintegrowanej Informatyzacji Państwa 2019–2022).

The governments of European Union Member States can assess the level of their e-development based on rankings that measure digitalisation in public services. DESI (Digital Economy and Society Index) is one such ranking applied in the European Union. Since 2015, the European Commission has been charting the Member States' progress in the field of digitalisation through its Digital Economy and Society Index (DESI) reports. The DESI quantified data contained in the DESI country reports is comprised of five dimensions for evaluating a country's digital economy and society, namely: connectivity, which includes fixed broadband uptake, fixed broadband coverage, mobile broadband and broadband prices; human capital for assessing the skills of Internet users and advanced skills; the use of online services, expressing the level of citizen's use of online services and their online transactions; and integration of digital technology for assessing the digitalisation level of business and e-commerce as well as digital public services, which, in turn, reflects the level of e-administration in a particular country. The Digital Public Services indicator comprises five criteria for assessing the digitalisation of the public sector: e-government users, pre-filled forms, digital public services for citizens, digital public services for businesses, and open data. Table 1 shows the DESI index for Poland over the last six years.

In terms of digital public services, Poland, despite stepping up its efforts to digitalise its public sector, especially in 2020, remains at the lower level of the

Tab. 1. Digital public services in 2017–2022

Year	Result — Poland	Result — EU average	Poland's position in the EU ranking
2017	45.4	54	19
2018	45.2	57.9	25
2019	52.5	62.9	23
2020	67.4	72	20
2021	55.1	68.1	22
2022	55.8	67.3	22

Source: Digital Economy and Society Index (DESI). Poland. Country Report (2019, 2020, 2021, 2022).

Tab. 2. Leaders and outsiders in digital public services in 2021

Indicator Digital Public Services	Leaders	Outsiders
E-government users	Sweden, Denmark, Finland, Ireland and the Netherlands fared very well, with over 90 % of Internet users (aged 16–74) choosing government websites when interacting with the public administration	Romania, Bulgaria and Italy fared less well in this dimension and were the only three countries where the percentage of citizens interacting with the public administration was below 50 %
Pre-filled forms	In 2021, the best performers were the Netherlands, Lithuania, Finland, Estonia, Malta, Denmark and Sweden, all of which achieved scores above 85 points	The worst-performing countries were Romania (below 20 points), Cyprus and Croatia (below 40 points)
Digital public services for citizens	Malta, Luxembourg and Estonia performed best in this area, achieving more than 90 points	Romania, Greece, Cyprus, Poland and Bulgaria scored less than 60 points
Digital public services for businesses	In total, seven countries (Ireland, Estonia, Malta, Luxembourg, Spain, Lithuania and Finland) scored more than 90 points (out of 100)	Romania, Greece, Croatia and Poland scored less than 70 points
Open data	A total of 11 countries (France, Ireland, Spain, Poland, Estonia, Austria, Italy, Slovenia, the Netherlands, Cyprus and Denmark) scored above 90 %	Slovakia, Malta, Belgium and Hungary scored below 60 %

Source: Digital Economy and Society Index — Digital public services (2022).

EU rankings, and its performance deviates significantly from the EU average. In the last year in the series, i.e., 2022, e-government services were used by 55 % of Internet users (an increase over the previous year), and this result was slightly closer to the EU average of 64 %. In the case of pre-filled forms, Poland's score (74/100) is considerably higher than the EU average (64/100), but when it comes to citizens' access to digital online services, Poland's score (57/100) is still poor when compared with the EU average (75/100). The same is true when it comes to businesses' access to digital public services in Poland (70/100): the EU average is 82/100. What is noteworthy about this indicator is Poland's increasing maturity in terms of access to open data (95 %), which is well above the EU average of 81 % in 2022 (Digital Economy Index…, 2022).

Estonia, Finland, Malta, and the Netherlands are the leaders in terms of digital public services, while Romania, Greece, Bulgaria and Slovakia are the poorest performers (Table 2).

Estonia is the EU leader in terms of digital public services. Almost 90 % of Internet users in that country have access to e-government services. Its scores for digital public services of 92/100 for citizens and 98/100 for businesses are close to the maximum and well above the EU average. Pre-filled forms are also widely used in Estonia, and the authorities in that country are making many datasets available as open data. The country is often ranked as one of the most digitalised nations in the world and is often referred to as e-Estonia. The priority is now shifting in that country towards the quality and human-centric nature of these services. This is reflected in the recently announced Estonian Digital Agenda 2030, which sets a target of 90 % on the Digital Economy and Society Index (DESI) 2022 Estonia (Digital Economy and Society Index — Digital public services, 2022).

When discussing the tools for assessing the level of digitalisation in public administration, it is also important to bear in mind that in 2017, the European Commission published the European Interoperability Framework (EIF), which offers specific guidance in the form of 47 recommendations on how to create interoperable digital public services. Three pillars of the EIF were developed, which formed the basis of the EIF Monitoring Mechanism, which was designed to assess the level of EIF implementation in Member States. It is founded on a set of 71 Key Performance Indicators (KPIs) grouped under the three main EIF pillars: principles, layers and the conceptual model (Interoperability Framework Monitoring Mechanism, 2021). It is worth noting that this tool not only allows for a self-assessment of each country but also makes it possible to indicate possible areas of improvement.

Given its ambitious goal of ensuring that all key public services are online by 2030, the digital transformation of governments remains a top priority for the European Union. In this context, interesting conclusions can be drawn from the "eGovernment Benchmark 2022" report prepared by the consulting company Capgemini. In research conducted by Capgemini's consultants, the maturity of e-government was assessed according to four basic elements: user orientation, transparency, availability of technological improvements and international services. According to Capgemini's study, the European leaders in this field were Malta and Estonia, which confirms the conclusions of the DESI analysis that the digital governments of these countries are the most user-centric, transparent, technologically equipped and open to users from other European countries.

It is important to point out that digital maturity may vary depending on the level of public administration. With a few exceptions, central government service providers are more digitally mature than their local and regional counterparts. In Europe, 84 % of all government services are available online, compared with 71 % of regional services, while only 60 % of local services can be provided digitally. There are, of course, some exceptions to the rule that central administrations outperform regional or local administrations. Interestingly, those countries where the central administration is digitalising public services at the same pace or slower than the regional or local administration include Denmark, Iceland, the Netherlands, Slovakia and Poland (eGovernment Benchmark 2022 — Synchronising Digital Governments, 2022).

1.2. Progress in the digitalisation of public services in Poland at the local government unit's level

The increasing digitalisation of public administration in Poland is visible at the government and local government unit levels, although the dominant share in this respect is visible in the area of e-state. This is evident in specific solutions that were implemented with particular intensity during the COVID-19 pandemic. Vial (2019) provided a multifaceted presentation of the digitalisation process and the different types and effects of the implemented technologies. Based on an analysis of studies on the use of digital technologies in companies, he described the opportunities, potential, and risks of implementing digital solutions. According to Vial, implementation of the digital transformation process has led to changes in the following areas: structural (organisational structure, organisational culture, leadership, employees and their roles and skills) and value creation (value proposition, value shaping networks, channels, capabilities and the "ambidextrousness" of organisations). Among the barriers to digitalisation, he mentioned organisational resistance, inertia, and threats to security and privacy. On the other hand, digitalisation has a positive impact on operational efficiency, organisational results and social change. One issue that has not been addressed in this context is the use of digital technologies in public administration, particularly in local government units. Research on the impact of digitalisation on the quality of public administration work and the position and role of administration staff, improvements in processes or services performed by the public administration and the benefits and threats for users have recently been conducted in different parts of the world by, among others, Mina-Raiu, Melenciuc (2022), Ofoma (2021), Andersson et al. (2022), and Umbach and Tkalec (2022).

The implementation of digitalised, fully electronic public services in Poland is currently possible thanks to the "Trusted Profile" digital identity system, originally launched for a small group of recipients in 2011. Constantly being upgraded, it has become widely available with over 12 million users since the end of July 2021 (i.e., 12 milionów …, 2021). Thanks to the "Trusted Profile" option, citizens using the Gov.pl platform can submit electronic notifications, e.g., regarding their marital status or the birth of a child, without the need to visit a local government unit office (Digital Economy and Society Index

(DESI), Poland, Country Report, 2021). Simultaneously with the trusted profile option, banks and other entities with users identified at the national level have also introduced their own identification systems.

Secure communication between citizens and the public administration is also possible thanks to the mObywatel mobile application, introduced in October 2017, which guarantees rapid access to mDokumenty. This application currently allows the user to confirm, among other things, their identity, entitlements or car insurance (e.g., mLegitymacja for school students, mLegitymacja for university students, mPojazd, etc.) as well as access to e-prescriptions and e-referrals. This application is being expanded to include more and more new functionalities, e.g., access to mLegitymacja for old age and disability pension holders. At the end of April 2022, over 7.5 million Poles used this application (mObywatel ..., 2022).

When it comes to the digitalisation of local government offices, one application that has been developed as a useful tool for users is eGmina. It allows the residents of a municipality to search for news, interesting places, and zones available after logging in. Users log in via their trusted profile. The account of a logged-in user is shared with the account on the eNależności platform. A logged-in user has access to data from the domain systems presented on the eNależności website and has the option of making payments via the payment system (eGmina, 2023).

In addition, as the few Polish studies in this field have shown, national local government offices use various digital tools to manage both internal and external processes in contact with users, such as electronic document flow, electronic archive, automatic correspondence with customers, handling applications and online complaints, document coding, self-service points of contact with customers (eBOM), an electronic queuing system, automatic hotline, voice bot/chatbot, time recording based on network log-in, electronic recording/ordering/liquidation of fixed assets, electronic handling of HR matters, electronic ordering of IT services, meetings and online courses. They also make use of tools supporting the digital functioning of offices, such as cloud solutions, internal virtual networks, CRM systems, electronic worktime recorders, Big Data, machine learning, artificial intelligence, and social media (Kafel et al., 2021b; Miazga et al., 2022). It should also be noted that the degree to which digital tools are used in local government offices varies (Kafel et al., 2021b), as can be observed in Polish cities. For example, the following digital tools were used in large cities with greater frequency than in smaller cities: high-speed Internet, cloud services, ERP and BI systems, while staff are provided with equipment for remote work or for training ICT. On the other hand, the key barriers hindering the digital transformation of such offices may still include, most importantly, insufficient financial resources, staff resistance to change, the limited competences of public administration officials and the current law. Despite the obstacles, municipal offices are introducing more and more e-services for citizens, even though many of these are scattered over various sites and rarely allow the user to deal with an entire matter online (Miazga et al., 2022).

This article addresses the literature gap in the debate on the importance of digitalisation in the public sector and is aimed at contributing to research on the digitalisation of local government in Poland.

2. Research methods

An analysis of selected models developed for both enterprises and public organisations provided the basis for an original model for gauging the digital maturity of public administration institutions, both at state and local government levels. The proposed model distinguishes between six dimensions: digitalisation-oriented management (vision, mission and management strategy of public sector organisations), openness to the needs of stakeholders (partners), digital staff competences, process digitalisation, digital technologies (information and communication technologies, IT systems, cloud data, process automation, and network speed) and e-innovation. Representatives of the surveyed organisations were asked questions about each of the dimensions distinguished in the model. The study adopted the 7-point Likert scale (where 1 meant “definitely not” and 7 — “definitely yes”). The answers enabled the authors to assess the level of maturity of the surveyed entities according to the above scale, as presented in Table 3. The overall score for a single organisation is calculated as the sum of the average scores for individual dimensions divided by six (which is the number of dimensions included in the study).

To determine the level of digital maturity of a public sector organisation, an additional condition was also considered, namely, if the score in at least one dimension (out of six) fell below the minimum

Tab. 3. Scale of digital maturity of public sector organisation

Range	Degree of the organisation's digital maturity
7.00–5.67	Full digital maturity (FDM)
5.66–5.00	Very high degree of digital maturity (VHDM)
4.99–4.34	High degree of digital maturity (HDM)
4.33–3.67	Moderate degree of digital maturity (MDM)
3.66–3.00	Low degree of digital maturity (LDM)
2.99–2.34	Very low degree of digital maturity (VLDM)
2.33–1.00	Insufficient degree of digital maturity (IDM)

Source: Kafel et al. (2021a).

score for the level immediately below it (according to the adopted scale), the level of maturity should be lowered by one level. In addition, the authors proposed the rule that to move to a higher level of digital maturity, improvements had to first be made in certain activities, especially in those areas that received such a low score. These activities may be considered a priority from the perspective of the digitalisation of a public sector entity.

A score between 7.00 and 5.67 on the digital maturity scale meant that an organisation had reached full digital maturity. This condition was defined by the authors of the study as a model organisation with full digital maturity and, thus, was a model worth following. For an organisation to make the transition towards this model, its managers had to take actions within each of the six analysed dimensions.

The full research sample consisted of 142 public organisations operating in Małopolska. These included local government units (at both county and municipality levels), labour offices, the National Revenue Administration, social insurance institutions, social welfare centres, sanitary and epidemiological stations, and police and municipal guards. The surveyed entities operate at the regional and local levels, including the voivodeship, county and municipality levels. In total, 21 270 people were employed in the organisations included in the sample. To verify the digital maturity of local government units, 54 units operating at the municipality and county level in the Małopolska were covered in the research (42 Municipality Offices, 12 County Offices; return rate was 26.4 %). They employed 4 417 staff (an average of almost 82 people per unit). The data was collected in 2020–2021 with an online measurement tool. Our respondents represented a top management level (town/city mayors or organisation managers) and a high management level (deputy organisation managers or department managers), one person per unit.

3. Research results

A comparison of different parameters of digital maturity in a county and municipality (Table 4 and Fig. 1) leads to the general conclusion that a higher degree of maturity has been achieved in the county.

According to the scale adopted by the authors, the level of digital maturity of counties is moderately higher (score: 3.82), while in the case of municipalities, digital maturity remains low (score: 3.47). These differences are particularly significant when it comes to the concentration of management tasks based on digitalisation (4.17 in counties and 3.60 in communes) and the digital competences of employees (4.23 in counties and 3.75 in communes). The fewest differences were noted in the digitalisation of processes (3.38 in counties and 3.19 in municipalities) and digital technologies (4.40 in counties and 4.21 in municipalities). The reason for the narrow gap between the two levels of local government may be the use of earlier presented IT solutions, which are available to LGUs to handle administrative tasks outsourced to them, as well as standardised processes thanks to standardised tools, but also legal regulations.

Overall, the level of digitalisation should be assessed as moderate in counties and low in municipalities (most dimensions of digitalisation are at such levels). The two areas where digitalisation is lowest in both counties and municipalities are e-innovation (low level in counties and very low in municipalities) and digitalisation of processes (low both in counties and municipalities). In turn, the areas characterised by the highest levels of digitalisation are digital technologies (high in counties and moderate in municipalities) and the digital competences of staff (moderate in both groups). The latest observation indicates that the development of applied technologies is accompanied by increased competences, which should be assessed in a positive light.

As part of the study, the authors analysed the correlation between the dimensions of digital maturity and the effectiveness of local government units operating at the county and municipality levels. For this purpose, the authors used an efficiency indicator comprising three elements connected with the execution time of internal processes and matters related to individual customer service, as well as the number of errors and mistakes made (Cronbach's alpha for this indicator is 0.88). The correlation coefficients are presented in Table 5.

Tab. 4. Level of digital maturity in local government units in Małopolska

Dimensions of digital maturity and relevant items	Counties	Municipalities
Digitalisation-focused management	4.17 moderate	3.60 low
processes being modified to facilitate their digitalisation	3.67	3.33
significant sums from the budget are being regularly allocated to support the digitalisation of institutions	4.08	3.48
digitalisation strategy treated as a key element of an organisation's development strategy	4.83	4.19
a digitalisation strategy is being systematically implemented, and efforts are being made to ensure more effective use of public funds (e.g., reducing service costs per one applicant)	4.08	3.40
Openness to the needs of stakeholders	3.58 low	3.20 low
efforts being made to achieve a state in which customers can process most interactions via the Internet	3.75	3.48
use of modern IT infrastructure, e.g., automated self-service devices for customers, so-called touchpoints	3.42	3.07
stakeholders (including customers) are involved in the process of improving/designing how e-services are provided by a public sector organisation	3.33	2.93
the effects of digitalisation (efficiency, costs) are constantly monitored using indicators measuring, e.g., the time taken to perform a procedure, customer satisfaction, etc.	3.58	2.14
the external help/opinions of experts in digitalisation are sought	3.42	3.52
services provided by a local government unit are being made more accessible, and its client base (e.g., people with reduced mobility, people receiving benefits, recipients of "tourist vouchers" and similar benefits) is being expanded	4.00	4.05
Digital competences of staff	4.23 moderate	3.75 moderate
popularising among staff the use of information technology in information and communication processes	5.83	4.52
digital competences are treated as an important criterion for evaluating staff	4.50	4.19
staff digital competences are being systematically developed	4.00	3.88
a positive attitude towards the digitalisation of processes is being fostered among staff in public sector organisations	4.33	4.05
a system is in place for recruiting and retaining staff with a high level of digital competence ("digital talents")	2.50	2.12
Digitalisation of processes	3.38 low	3.19 low
primary data and processes connected with customer service are digitalised	4.25	3.33
most data and internal (auxiliary) processes (e.g., human resources, fixed asset records, data archiving) are digitalised	4.25	4.10
customer service processes are automated so that most can be performed with minimal staff involvement	2.42	2.40
internal processes (auxiliary processes, e.g., HR processes, fixed assets register, data archiving) are automated so that most can be performed with minimal staff involvement	2.83	2.74
efforts are being made to systematically reduce the costs of implementing processes/procedures using digitalisation and process automation	3.17	3.38
Digital technology	4.40 high	4.21 moderate
remote work is the standard mode for performing certain groups of tasks	4.00	3.67
IT systems used in local government units are fully integrated	3.67	4.00
all staff have unlimited access to IT support	5.58	5.24
use of dedicated software (adapted to the needs of the office)	3.83	4.21
systematic steps have been taken to ensure the protection and security of digital solutions	5.58	5.21
data stored in the "cloud" (or on proprietary virtual drives) is used to improve the efficiency of remote work	3.75	2.93
E-innovation	3.26 low	2.93 very low
data analytics software (e.g., artificial intelligence, so-called Big Data Management, Business Intelligence Tools) is used so as to better adapt to partners' expectations (offering individualisation)	1.75	1.33
innovative solutions based on the latest digital technology (use of "breakthrough" innovations, e.g., smart services)	3.08	2.17
processes using internal and external resources (e.g., start-ups, hackathons) are being systematically digitalised	2.58	2.36
e-innovations are sought at all levels of public sector organisations in accordance with the approach "we do not have to be ashamed of our ideas"	3.83	2.81
digitalisation and automation are helping (where possible) to increase the level of non-cash payments for benefits	4.08	5.31
efforts are constantly being made to increase the use of digital technologies	4.25	3.62

Tab. 5. Correlation coefficients

Dimensions of digital maturity	Efficiency	
	counties	municipalities
Digitalisation-focused management (α = 0.853)	0.953*	0.737*
Openness to the needs of stakeholders (α = 0.761)	0.889*	0.600*
Digital competences of staff (α = 0.731)	0.436^{ns}	0.674*
Digitalisation of processes (α = 0.737)	0.867*	0.508*
Digital technologies (α = 0.695)	0.942*	0.521*
E-innovation (α = 0.826)	0.865*	0.722*
Number of entities	12	42

ns — no statistical significance (p>0.05); * p<0.05; α — Cronbach's alpha coefficient

The results of the correlation analysis presented in Table 5 indicate a strong correlation between the dimensions of digital maturity and the effectiveness of local government units (in terms of infallibility and the time of the performance/execution of tasks), while in counties, the correlation coefficients are very high (with the exception of the digital competences of staff). Correlation coefficients are also high in municipalities (for all dimensions of digital maturity) but clearly lower than in counties. This suggests that the relationship between the dimensions of digital maturity and effectiveness is stronger in counties than in municipalities and that municipalities are only making limited use of the potential for digitalisation (much less so than counties). This, in turn, may provide the basis for recommendations on how to better utilise digitalisation to improve efficiency in municipalities, especially when it comes to digital technologies and the digitalisation of processes (in the latter case, the differences between counties and communes are greatest).

4. Discussion of the results

An analysis of the correlation between the dimensions of digital maturity and effectiveness confirms the observations made by Hofmann et al. (2012), namely that implementing e-government solutions requires the acceptance of a wide range of stakeholders, including citizens, entrepreneurs and administration employees. One of the dimensions of digitalisation in the proprietary model is openness to the needs of stakeholders. However, the results of the present analysis show that in this area, the level of maturity in the examined LGUs is relatively low, especially at the municipality level.

The problem addressed in this study is part of the current discourse on the importance of digitalisation in the public sector. In particular, it makes a valuable contribution to research on digitalisation in local government in Poland, which is part of the implementation of Digital Era Governance goals. Urs and Spoaller (2022) regarded ongoing digitalisation as a form of progress and development, which is transforming public administration into an entity that guarantees users high-quality services and a higher quality of life. This viewpoint confirms the conclusions previously formulated by Pelse et al. (2021), who point out that the factors driving digitalisation in public institutions are technological progress and society's desire for novelty and high-quality modern services.

Moreover, this process is fostered by education. Digitalisation in public institutions cannot exist without technological progress, and the opportunity to exploit it; a willingness to change is also necessary. This willingness is often fuelled by the pressure of public opinion, and the dividing line between the physical and digital worlds will become increasingly blurred (Pieterson et al., 2017). At the same time, digital transformation involves not only the implementation of technology elements but also certain social, political and organisational factors (Gardenghi et al., 2019). This is fully in line with the position of Dunleavy et al. (2006), who considered the effects of digital transformation broadly, focusing not only on technological but also organisational, cultural and social change.

While the concept of New Public Management still plays a central role in Poland, its importance is decreasing in many countries, and a scenario whereby in the coming years DEG and EDGE are applied on a wider basis in public management practice seems very likely (Dunleavy et al., 2005).

However, there is a noticeable risk that the reintegration of administrative structures resulting from digitalisation could lead to staff reductions, which would still not solve the problem of different departments of an organisation ("silos") hindering effective information management in citizen-local government official relations. Another consequence of the new conditions is that decision-makers need to resolve numerous dilemmas arising from digitalisation processes and governance that is more citizen-centred, transparent and participatory, which at the same time is more vulnerable to security, misinformation, and inequality (Milakovich, 2021). The authors fully agree with the thesis that the large-scale implementation of DEG must be followed by the internal and external opening up of national and local governments, which in turn will lead to much less complicated structures of public administration, characterised by the simplification and automation of everyday bureaucratic work and the more flexible provision of services (Dunleavy et al., 2005). The activities of public administration must now be closely linked to the increasing autonomy of citizens and their capacity for social problem-solving (Białożyt, 2017). Greater effort is needed to keep pace with citizens immersed in the digital world who use social media and online discussion platforms not only as their primary source of information but also as a more reliable source than that offered by the public administration in its current bureaucratic form.

The lack of sufficient competences when it comes to the digitalisation of public services will result in a situation where the public administration will be unable to communicate effectively with citizens, which may undermine the trust of the latter (Dunleavy & Margetts, 2015; Milakovich, 2021). Implementing the goals of Digital Era Governance in public administration practice can, according to the authors of the article, prevent or at least mitigate such dangers.

Conclusions

The study joins a debate on whether and how quickly the concepts of DEG and EDGE can be implemented in local public administration in Poland. Under Polish conditions, managers have adopted a selective approach and still refer to the notion of NPM, as evidenced by the relatively low level of digital maturity of the surveyed local government units. The development of DEG and EDGE has been limited by Neo-Weberian State and New Public Governance supporters, which still enjoy a dominant position in Polish public administration practice.

The added value of the article lies in the fact that it determines the degree of digitalisation in public administration entities at the local government level. These studies contribute to a small set of experiences aimed at identifying local governments' digitalisation level. The original research model, verified in practice based on local administration, has a pioneering character and is a significant addition to the tools used to measure the level of maturity of public sector organisations. The research showed that digitalisation was less advanced in municipalities than in counties. In addition, it was found that e-innovation and digitalisation are the least developed areas in this context. The recommendation, therefore, is to further develop digitalisation in local government units (LGUs).

The research has several limitations, primarily resulting from its sample (it was performed only among selected LGUs in the Małopolska region that expressed a willingness to participate). The authors intend to use their experiences with applying the model in selected public institutions (LGUs), prepare the next version of this model and test it on a larger research sample.

The differences observed in the correlation coefficients between the dimensions of digital maturity and effectiveness between counties and municipalities suggest a legitimate need for further research using more advanced analytical methods (and, thus, the need to research larger samples). Such studies must be replicated regularly to keep pace with a rapidly changing field. Similar studies are recommended to be replicated in other contexts (different types of public organisations, different levels of public administrations, and different regions) to validate and improve the proposed digital maturity model. Further research should consider the evolution of DEG towards EDGE; this will make it possible to understand the mechanism behind increasing digital maturity in public administration.

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Supervised multilabel classification techniques for categorising customer requirements during the conceptual phase in the new product development

Sutrilastyo
Ririn Diar Astanti

ABSTRACT

The research aims to provide the decision-maker with a framework for determining customer requirements during product development. The proposed framework is based on sentiment analysis and supervised multilabel classification techniques. Therefore, the proposed technique can categorise customer reviews based on the "product design criteria" label and the "sentiment of the review" label. To achieve the research goal, the research presented in this article uses the existing product development framework presented in the literature. The modification is conducted especially in the conceptual stage of product development, in which the voice of the customer or a customer review is obtained from the scraping, and a multilabel classification technique is performed to categorise customer reviews. The proposed framework is tested by using the set data on women's clothing reviews from an e-commerce site downloaded from www.kaggle.com based on data by Agarap (2018). The result shows that the proposed framework can categorise customer reviews. The research presented in this paper has contributed by proposing a technique based on sentiment analysis and multilabel classification that can be used to categorise customers during product development. The research presented in this paper answers one of the concerns in the categorisation of needs raised by Shabestari et al. (2019), namely, the unclear rules or main attributes of a requirement that make these needs fall into certain categories. Categorising customer requirements allows decision-makers to determine the direction of product development to meet customer needs.

KEY WORDS

voice of customer, customer needs, conceptual design, product development process, customer's requirement categorisation, sentiment analysis, supervised multilabel classification technique

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Ririn Diar Astanti

Universitas Atma Jaya Yogyakarta, Indonesia
ORCID 0000-0001-5234-0283

Corresponding author:
e-mail: ririn.astanti@uajy.ac.id

Sutrilastyo

Universitas Atma Jaya Yogyakarta, Indonesia

Introduction

New product development (NPD) can be described as a formalised planning process that encompasses the steps from initial idea generation to product launch in the market (Kim et al., 2016). New product development is critical to supporting business growth (Cooper, 2001; Ulrich & Eppinger, 2015). The popular new product development (NPD) stage consists of several stages, such as the initial product concept or idea that is evaluated, developed, tested, and launched on the market (Booz et al., 1982;

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Büyüközkan & Arsenyan, 2012; Kaulio, 1998; Shabestari et al., 2019; Ulrich & Eppinger, 2015). During the conceptual phase, the ideas are developed into product specifications or dimensions, such as product features, design, and durability (Di Benedetto, 1999; Schulze & Hoegl, 2006). The conceptual design stage is crucial in the product development process as it identifies customer needs. Later, if considered during product development, these needs can provide a competitive advantage for the company (Bhuiyan, 2011).

One example of consumer needs that should be considered during the conceptual phase is related to product design. According to Kreuzbauer and Malter (2005), attractive product designs impact the image and positive brand for customers. The product failure risk can be reduced by considering the voice of the customer (VoC) in the product design and development process (Nazari-Shirkouhi & Keramati, 2017). VoC and value derived from a product are also essential quality aspects (Kapucugil Ikiz & Özdağoğlu, 2015; Mulay & Khanna, 2017). VoC contains the expectations and needs that customers feel for a product or service. Obtaining VoC for a company is a crucial activity (Aguwa et al., 2017).

Several methods for obtaining VoC are surveys, interviews, and focus group discussions (Kapucugil Ikiz & Özdağoğlu, 2015; Šperková, 2019). However, these methods face several obstacles in many situations, such as cost efficiency, time, and space constraints. To overcome these limitations, several previous studies (Devi et al., 2016; Jeong & Yoon, 2016; Misopoulos et al., 2014) collected VoC through media on the Internet, such as product reviews, forum discussions, and social media.

One of the methods to analyse VoC is text mining. According to Khedr et al. (2017), text mining is a method for extracting knowledge from text. Pinquié et al. (2018) used text mining to obtain the quality requirements of documents. Text mining was used by Lee and Bradlow (2011) to extract information from customer reviews and then cluster it into groups. Kapucugil Ikiz and Özdağoğlu (2015) suggested that text mining techniques help speed up the VoC collection process.

One of the text mining methods used to identify VoC is sentiment analysis. Sentiment analysis is one of the text mining methods used to determine the contextual polarity of an article, whether negative, neutral, or positive (Shukri et al., 2015). The use of sentiment analysis, as described by Jeong and Yoon (2016), can identify features that can be further developed on smartphones. Huang et al. (2013) used a multi-task and multilabel classification approach in conducting a sentiment analysis and topic classification on the Twitter platform. The study found that sentiment labels helped in the process of accurately distinguishing topics. Other researchers stated that sentiment analysis is used to identify the weaknesses of products reviewed by customers (Zhang et al., 2012) and to measure customer satisfaction (Kang & Park, 2014).

Shabestari et al. (2019) summarised studies using Machine Learning (ML) and text-mining techniques in the initial stages of product development. Most of the literature uses one of the unsupervised learning techniques in the product requirements categorisation stage using ML. Only one study used supervised learning techniques. Research using the supervised learning method in the needs categorisation stage has not been widely carried out. Meanwhile, according to Edwards et al. (2021) and the research results by Abad et al. (2017), classification using supervised learning techniques tends to be more accurate when compared to unsupervised learning techniques. In addition, Shabestari et al. (2019) also stated that there were no studies comparing the performance of one classification/clustering method with another.

Although sentiment analysis can be used by designers to quickly obtain customer preference data, both qualitatively and quantitatively, the insights obtained from these sentiments are still limited (Ireland & Liu, 2018). This is because the characteristics of certain features of a product cannot be known. Therefore, to fill this gap, adding a parameter that can show the characteristics of a product's features, e.g., by using product criteria, is considered in the proposed framework presented in this paper. The research proposed in this paper tries to fill the existing gaps by categorising customer requirements based on the "product design criteria" label and "sentiment of the review" using a supervised multilabel classification technique.

1. Literature review

This chapter discusses previous research on Voice of Customer (VoC) and the use of Sentiment Analysis and Machine Learning (ML) during product development.

1.1. Product development process

Product development is a vital part of maintaining the competitiveness of any organisation. This process determines product specifications and production processes by considering market needs, technology availability, and the organisation's strategy (Kim et al., 2016). Ulrich and Eppinger (2015) defined product development as a series of activities that begin with identifying market opportunities and end with product production, sales, and delivery. They divided the product development process into several stages: planning, concept development, system-level design, detail design, testing and refinement, and production. These are divided into several smaller stages. For example, concept development is divided into stages of identifying customer needs, determining product specifications, generating product concepts, and conducting concept tests. Conceptual design deals with how needs are identified and the formulation of product design concepts. The prototype tests the proposed concept, and the product launch is related to the product commercialisation process.

Kaulio (1998) also divided the product development process into five phases: specification, concept development, detailed design, prototype, and final product. Büyüközkan and Arsenyan (2012) proposed similar stages in their research on collaborative product development. Pienaar et al. (2019) used a stage-gate model where product development consists of four "gates" and four stages, i.e., the exploration stage, where ideas are conceptualised; the assessment stage, where opportunities are defined; the research stage, where the pilot/first technology development is carried out, and the last stage is implementation preparation where the pilot technology commercialisation trial is made.

Various stages of new product development are suggested in the studies mentioned above. According to Carter (2015), no one best product development stage can outperform other product development stages. In general, product development stages can be grouped into three major groups: conceptual design, prototype, and product launch. The grouping of the stages proposed by previous researchers into three major groups of product development stages can be seen in Table 1.

According to Shabestari et al. (2019) and Kornish and Hutchison-Krupat (2017), the conceptual design consists of several stages: (1) requirement identification; (2) requirement categorisation; and (3) conceptual selection, especially the requirements categorisation during product development. During the requirements identification, the Voice of Customer (VoC) is needed.

VoC contains consumer expectations and needs for products, and these expectations help companies in the process of developing their products or services (Aguwa et al., 2017). VoC is a valuable resource for companies. The methods used to collect VoC can be in the form of surveys, interviews, focus group discussions, and other methods (Kapucugil Ikiz & Özdağoğlu, 2015; Šperková, 2019).

With the development of technology, the platforms for VoC are also increasing. Social media and e-commerce platforms, such as Facebook, Twitter, Reddit, YouTube, Amazon, and Tokopedia, are used to collect data in the form of user posts, reviews, and comments. The feedback that customers give voluntarily on these platforms is a key factor in the product development and design phase (Park et al., 2018). In addition, data taken from social media is used for various purposes, such as predicting the company's popularity level based on consumer reactions on social media (Park & Alenezi, 2018). Gupta and

Tab. 1. Product development stages

Author	Product Development Stage		
	Conceptual design	Prototype	Product launch
Ulrich & Eppinger (2015)	• Planning • Concept development • System-level design	• Detail design • Testing and refinement	• Production ramp-ups
Kaulio (1998)	• Specification • Concept development	• Detailed design • Prototyping	• Final product
Büyüközkan & Arsenyan (2012)	• Conceptual design	• Product development • Prototype	• Manufacturing • Product launch
Pienaar et al. (2019)	• Explore • Assess	• Research	• Prepare for implementation

Sebastian (2018) looked at the performance of a product in the market based on ratings and reviews provided by users, and Zhou et al. (2016) compared consumer behaviour when shopping online.

After requirement identification, the next step in the conceptual stage of product development is requirement categorisation, which is processing the feedback from the requirement identification step. Large amounts of data are one of the obstacles in processing data obtained from online platforms, such as social media and e-commerce. Obtaining useful and meaningful information from the data is a challenge. Text mining helps bridge this process. Jeong and Yoon (2016) used text mining to get VoC and find development opportunities in smartphone products. Park et al. (2018) used sentiment analysis to find more important features in improving tire design.

1.2. Sentiment analysis

Sentiment analysis is also known by several other names, such as opinion mining, sentiment mining, and opinion extraction. It is a process of detecting and classifying the contextual polarity of the text (Micu et al., 2017). There are two kinds of sentiment analysis approaches: ML-based sentiment analysis and lexicon/dictionary-based sentiment analysis. ML-based sentiment analysis often involves a model assigning labels to data based on data used to train the model. Meanwhile, lexicon-based sentiment analysis uses pre-determined words, where each word is associated with a certain sentiment (Gonçalves et al., 2013).

Several methods often used to perform ML-based sentiment analysis are classification methods, such as Support Vector Machine (SVM) and Naïve Bayes (Kolchyna et al., 2015). Other methods, such as Maximum Entropy (ME), Logistic Regression, Apriori, and Random Forest, were also used in several other studies (Malviya et al., 2020; Samuel et al., 2020). Devi et al., 2016 used SVM to determine user perceptions of features from reviews of several laptop brands.

According to Ireland and Liu (2018), the insights obtained from the sentiment analysis are still limited. The result from sentiment analysis cannot identify the characteristics of a product's certain features. Therefore, to fill this gap, adding a parameter that can show the characteristics of a product's features, for example, by using product criteria, is considered in the proposed product development framework presented in this paper. Shabestari et al. (2019) summarised previous studies on using ML in the initial stages of product development. Among these studies, 51 use the ML method, both supervised and unsupervised learning methods. Twelve studies focus on the needs categorisation stage: 11 use the unsupervised learning method, and one — the supervised learning method. Aguwa et al. (2017) used a clustering technique to group keywords that play a key role in the quality of customer reviews. Fuzzy logic is then combined with the clustering model to capture the main essence of customer reviews so that the fulfilment of customer needs for products or services can be improved. Lee and Bradlow (2011) conducted text mining to get the pros and cons of customer reviews. The clustering process is carried out on the pros and cons attributes to divide the words into special categories. The process can reveal the position of the product compared to competitors or related products and highlight product attributes that stand out in the eyes of customers. Abad et al. (2017) classified customer needs into two categories: functional/functional requirements (FR) and non-functional/non-functional requirements (NFR). The research found that the classification of NFR into sub-categories, such as usability, availability, and performance, can be automatically improved by using ML. The proposed product development framework presented in this paper is adapted from Shabestari et al. (2019) and Kornish and Hutchison-Krupat (2017) by adding sentiment analysis considering the "product design criteria" label and "sentiment of the review" using supervised multilabel classification technique during the requirement categorisation process in the conceptual stage of the product development process.

2. Proposed framework

This research focuses on the conceptual design stage, especially the requirements categorisation process during product development. As mentioned in the previous section, the proposed product development framework presented in this paper is adapted from Shabestari et al. (2019) and Kornish and Hutchison-Krupat (2017). The modification has been made by adding sentiment analysis considering the "product design criteria" label and "sentiment of the review" using a supervised multilabel classification technique during the requirement categorisation

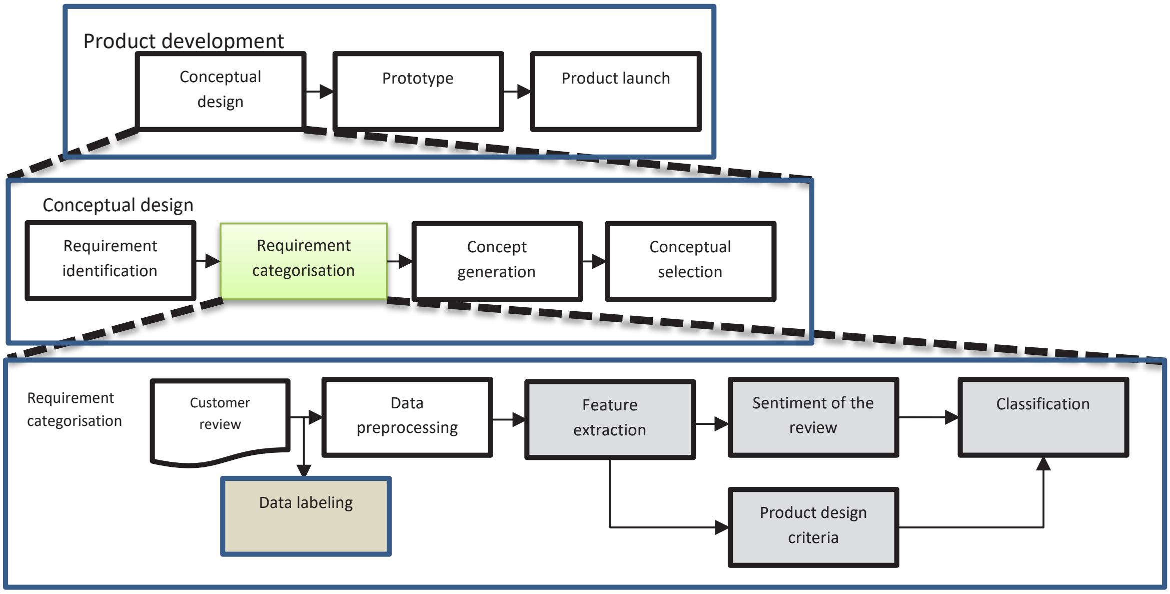


Fig. 1. Proposed framework for requirement categorisation in the product development process

process in the conceptual stage of the product development process.

The proposed framework is presented in Fig. 1. During the requirements categorisation process in the proposed framework, the categorisation process starts when the Voice of Customer (VoC) or a customer review is received from the identification process. The requirement categorisation step is performed next. The categorisation requirement steps consist of several activities: data labelling, data pre-processing, feature extraction, and classification. The difference between the framework proposed in this paper and the previous research is that during the requirement categorisation process:

- Customer review data is firstly labelled according to "product design criteria" and "sentiment of the review" before the pre-processing.
- Multilabel classification technique is based on "product design criteria" and "sentiment of the review". This approach has not been found in previous research. "Product design criteria" and "sentiment of the review" are the Feature Extraction results. The purpose of using multilabel classification in the need categorisation stage is to assist decision-makers in categorising customer needs based on one aspect of a product and customer perceptions of that aspect. Thus, this will assist in the stage of making product design concepts that can meet customer needs/wants. There are three classification techniques used to classify customer needs: Naïve Bayes, Logistics Regression, and Support Vector Machine. Among those three techniques, one has the highest accuracy and is selected as the classification technique in the proposed framework presented in this paper. The result from these classification techniques will be used as input for the next stage of the product development process, which is concept generation.

Details of each step in the proposed framework are presented in the following subsections.

2.1. Getting a customer review by web scraping techniques

As presented in the proposed framework in Fig. 1, especially during requirement categorisation, the step starts by getting customer product reviews using web scraping techniques. Web scraping is a process for automatically extracting and organising data from web pages (vanden Broucke & Baesens, 2018).

2.2. Data labelling

The obtained data is then labelled as "product design criteria" and "sentiment of the review". For example, women's clothing has four "product design criteria" classes consumers consider when deciding on a product.

2.3. Pre-processing data

According to Lai and Leu (2017), data pre-processing uses a desired analytical method to obtain good quality and efficient data analysis results by eliminating inconsistent, abnormal, and erroneous data. Several activities are performed during the pre-processing step, including checking missing data, inequalities, tokenisation, stop words, and stemming.

2.3.1. Checking missing data

After the data is imported, the next step is to ensure that no data (values) are missing from each column/variable because they can negatively affect the classification prediction results (Haq et al., 2019). In the research presented in this paper, the function used to check the missing data is df.isnull().sum().

2.3.2. Checking inequalities

This step was performed to prepare the training set data and test set data for classification steps. The purpose is to check if there is an inequality in the number of labels on the "product design criteria" and "sentiment of the review" variables. This step is important because the classification accuracy is strongly influenced by the balance of the data amount. The model trained using unequal data has low accuracy because it tends to predict data to classes with more numbers. A large amount of data cannot improve the classification results if the problem of data inequality is not addressed (Li et al., 2011; Shen et al., 2019). The function used to handle inequality is df['Criteria'].value_counts() and df['Sentiment'].value_counts().

2.3.3. Tokenisation, stop-word removal, and stemming

Tokenisation is dividing text into a series of words called tokens. Stemming is changing words into their basic form by removing affixes. Eliminating affixes can increase recall (the model's ability to identify true positives) (Issac & Jap, 2009). Stop-word removal is removing words without a significant meaning in the text (Khedr et al., 2017). In this proposed framework, pre-processing data is performed using Python. The stop-word removal activity used the stop-word library from the "nltk" package in Python. NLTK (Natural Language Toolkit) is a platform for processing human language data in Python (Bird et al., 2009). The stemming process is done by defining a function using Porter Stemmer from NLTK and then applying that function to the review text. Porter Stemmer is a stemming algorithm that removes common morphological endings and inflections from words in English (Issac & Jap, 2009).

2.4. Feature extraction

Feature extraction takes a list of words from text data and converts it into a set of features that can be used by the classifier (Waykole & Thakare, 2018). The feature extraction technique used was frequency-inverse document frequency (TF-IDF). TF-IDF measures the relevance of a term in a document. Where $w_{i,j}$ is the weight of term i in document j, N is the number of documents, $tf_{i,j}$ is the frequency of term i in document j, and df_i is the frequency of documents of term i, then the weighting of terms in TF-IDF can be formulated in the following equation (Zhang et al., 2011):

$$w_{i,j} = tf_{i,j} \times log\left(\frac{N}{df_i}\right). \qquad (1)$$

The first step is to use the "CountVectorizer()" function from the "sklearn" library. This function converts a text into a vector based on the frequency of each word that appears in the text. After converting into vector form, the next step is to perform TF-IDF using the "TfidfTransformer()" function from the "sklearn" library. The main purpose for using TF-IDF in calculating the number of tokens that appear in a document compared to the "raw frequency" is to reduce the impact of tokens that appear frequently in documents. These frequent tokens are empirically less informative when compared to tokens that appear in small fractions (Pedregosa et al., 2011). After the data is transformed into a TF-IDF array, the next step is to divide the data into two data sets: training data and test data. The training data is used to train the created classification model. The distribution of the dataset uses a ratio of 80 % for training data and 20 % for test data based on suggestions by Rácz et al. (2021).

2.5. Classification

After the feature extraction, the classification technique is applied based on "product design criteria" and "sentiment of the review". Because the technique proposed in the research presented in this paper is supervised learning, the data is divided into a training set and a test set. Usually, there is a problem related to data inequalities leading to data discrepancy when deciding which data are categorised as a training set and a test set. The data discrepancy makes the classification model biased towards a larger number of classes, resulting in poor model performance (Guo et al., 2019). The Synthetic Minority Oversampling Technique (SMOTE) method is used to overcome this inequality. Elreedy and Atiya (2019) described the SMOTE stages as follows:

- For each X_0 pattern of the minority class, do the following:
  - Choose one of the K closest neighbours to X (nearest neighbours), who are also a minority class.
  - Create a new pattern Z at a random point on the line segment connecting the pattern and the selected neighbours. Z is formulated as:

$$Z = X_0 + \omega(X - X_0), \quad (2)$$

where ω is a random variable that is uniformly distributed U [0,1].
The SMOTE method is performed using the "SMOTE()" function in the "imblearn" library

- After the data discrepancy is resolved, sentiment classification and criteria are carried out on the training data set.

The proposed framework compared three supervised Machine Learning classification techniques: Naïve Bayes classification (Kang & Park, 2014; Povoda, 2016), Logistic Regression (Pranckevičius & Marcinkevičius, 2017; Shah et al., 2020; Wang et al., 2017), and Support Vector Machine (SVM) (Hadi et al., 2018; Jiang et al., 2013; Singh et al., 2019; Tan et al., 2009). After the classification model is trained, the results are validated using a test data set to run the trained model. The validity of the model is measured by the level of accuracy given by the model using the test data set. The model of the classification technique with the best performance was chosen as the reference classifier model.

2.6. Interpreting the result from the categorisation requirement process

In this step, the result in the categorisation requirement process started from getting the customer review, data labelling, feature extraction and classification, interpreted to give an insight that can be used by the company to identify the criteria considered by the consumer in buying a certain type of product.

The result is presented using a data visualisation technique so that it is easier for the company to understand.

3. Case study: customer reviews of women's clothing in e-commerce

This section discusses the application of the framework proposed in a case study. The selected case study is a customer review of women's clothing on an e-commerce site.

3.1. Getting a customer review by web scraping techniques

To illustrate the applicability of the proposed framework, data on women's clothing reviews from an e-commerce site are used. The data is downloaded from www.kaggle.com based on data by Agarap (2018). This data consists of ten variables. Among the ten variables provided in the data set, the research presented in this paper uses the "Review Text" variable, which contains reviews from each user as shown in Table 2.

3.2. Data labelling

There are two labels used to mark the review text by the user: "product design criteria" and "sentiment of the review". Each label has four and three classes, respectively. The label "sentiment of the review" has three classes: "positive", "neutral", and "negative", indicating whether a review is positive, neutral, or negative. Four classes of the "product design criteria" are taken from Eckman et al. (1990) on the four main criteria that consumers consider when deciding to buy women's clothing. The four criteria can be seen in Table 3.

The class of the "product design criteria" label is determined by looking at the tendency of user reviews towards one of the sub-criteria listed in Table 3. If the review meets one of the sub-criteria, then the class assigned to the label "product design criteria" in the review is the criteria related to the sub-criteria.

For example, the review "This shirt is very flattering to all due to the adjustable front tie. It is the perfect length to wear with leggings and it is sleeveless, so it pairs well with any cardigan. love this shirt!!!" discusses how the shirts purchased by users are very suitable when paired with leggings and cardigans. This relates to the "matching" sub-criteria, so the class

Tab. 2. Description column name

No	Column name	Description
1	Clothing ID	An integer variable that refers to one of the items under review
2	Age	Age of the user who gave the review
3	Title	The title of the user-generated review
4	Review Text	Contents of user-generated reviews
5	Rating	The value assigned by the user for the product being reviewed. The range of values given is from 1 (worst) to 5 (best)
6	Recommended IND	A variable that states whether the user recommends the product or not
7	Positive Feedback Count	A variable that shows the number of other users who consider the reviews made positive
8	Division Name	Name of the division of the product under review
9	Department Name	Name of the department of the product under review
10	Class Name	The class name of the product under review
11	Clothing ID	An integer variable that refers to one of the items under review

Tab. 3. Criteria for women's clothing

Criteria	Sub-Criteria	Definition
Aesthetic	Colour/pattern	Relates to the colour, print, or visual pattern of clothing
	Styling	Associated with the design of clothing that includes the fashionable, style, or individual preference for a type of clothing
	Fabric	Relates to the material and content of the fabric used to make clothes
	Uniqueness	Associated with the uniqueness, unusualness, and rarity of clothing
	Appearance	Relates to how the clothes look to the user: attractive vs. not attractive appearance
Usefulness	Versatility	Relates to the adaptability of clothing to various uses or situations
	Matching	Relates to the suitability of clothes when paired with other clothes
	Appropriateness	Relates to the suitability of clothing for a particular social and occupational environment
	Utility	Related to the ability of clothing to meet the needs of certain clothes from its users
Performance and quality	Fit	Relates to the suitability of clothes to the body shape
	Comfort	Relates to how the clothes and the material of the clothes are perceived by the wearer
	Care	Relates to how the clothes are taken care of by the wearer
	Workmanship	Relates to the superiority of construction/manufacture or material of clothing
Extrinsic	Price	Relates to the price of the clothes
	Brand	Associated with the name of the clothing maker or brand of the clothing
	Competition	Relates to the availability of the same type of clothing in other stores

for the "product design criteria" label assigned to the review is "usefulness". The class assigned to the "sentiment of the review" label was "positive" because the review was positive, marked by the words "This shirt is very flattering…" and "… love this shirt!!!".

3.3. Pre-processing data

Data pre-processing activity was performed before proceeding to the feature extraction steps. This step was conducted to process the data to the appropriate form for further analysis. Pre-processing in the research proposed in this paper is mostly done using Python through the Google Collaboratory/Google Colab platform. This paper does not explain tokenisation, stop words, and stemming in detail because those are common steps in text mining methods.

3.3.1. Checking missing data

The function used to check the missing data is df.isnull().sum(). The result is presented in Fig. 2.

```
Review Text    0
Kriteria       0
Sentiment      0
dtype: int64
```

Fig. 2. Result from checking missing values

3.3.2. Handling inequality

The functions used to handle inequality is df['Criteria'].value_counts() and df['Sentiment'].value_counts(). The result is presented in Figs. 3 and 4.

```
Performance and quality    1310
Aesthetic                   722
Usefulness                  135
Extrinsic                    42
```

Fig. 3. Check the balance data for the "product design criteria" variable

```
Positive    1611
Neutral      300
Negative     298
```

Fig. 4. Check the balance of data for the "sentiment of the review" variable

Based on Figs. 3 and 4, there is a disparity in the number of classes on both the "product design criteria" label and the "sentiment of the review" label. The "product design criteria" label is dominated by the "performance and quality" class, followed by the "aesthetic" class. "Sentiment of the review" is dominated by the "positive" class.

3.3.3. Tokenisation, stop-word removal, and stemming

Several activities performed in this step include the removal of punctuation, stop words and stemming.

3.4. Feature extraction

As mentioned in Section 3.3.2, there is an imbalance in the number of classes from the labels "product design criteria" and "sentiment of the review". Therefore, the SMOTE method was used to address this inequality. By overcoming data inequality, it is hoped that there will be no overfitting in the classification model that will be made.

The amount of data for each class before the data inequality is overcome can be seen in Fig. 5.

Based on Fig. 5, the amount of data in each class of the two labels becomes the same after applying the SMOTE method.

3.5. Classification

In this step, the proposed multilabel classification technique used "product design criteria" and "sentiment of the review", which has not been done in three supervised machine learning techniques for classification. Multilabel classification technique is based on "product design criteria" and "sentiment of the review". This sub-section discusses the performance of the selected Machine Learning (ML) classification techniques: Support Vector Machine, Naïve Bayes, and Logistic Regression.

3.5.1. Support Vector Machine (SVM)

The SVM model is imported from the "sklearn" library. Data training is done using the "model.fit()" function from the "sklearn" library. The variable "x_train", which contains the review text from consumers, is used as a predictor variable, and the variable "y_train" is used as the response variable.

The response variables are the labels "product design criteria" and "sentiment of the review" so that the model training is carried out once each for both labels. After the model is trained, the next step is to

```
Before OverSampling, counts of label Performance and quality is: 1041
Before OverSampling, counts of label Aesthetic is: 571
Before OverSampling, counts of label Usefulness is: 115
Before OverSampling, counts of label Extrinsic is: 40
Total number of rows: 1767

Before OverSampling, counts of label is Positive: 1286
Before OverSampling, counts of label is Negative: 237
Before OverSampling, counts of label is Neutral: 244
Total number of rows: 1767
```

Fig. 5. Total data before inequality is overcome

calculate the accuracy of the model using the test data set. The number of test data from the split results is 442 for the "product design criteria" label and 302 for "sentiment of the review". Accuracy is calculated by comparing the result label predicted by the model with the actual label. Prediction of the SVM model for the "product design criteria" label can be seen in Fig. 6.

From Fig. 6, the results of the accuracy measurement of the SVM model for the "product design criteria" label give an accuracy value of 62.2 %. The f1-score indicates what percentage of the predicted label corresponds to the actual label. Furthermore, the prediction of the SVM model for the "sentiment of the review" label can be seen in Fig. 7.

From Fig. 7, the accuracy obtained from the model is 76.0 % with precision and recall values for the "negative", "neutral", and "positive" classes are 0.56 and 0.57; 0.26 and 0.25; and 0.88 and 0.88, respectively. An example of a neutral tone of review can be seen in Table 4.

Of the 61 "negative" data, 35 were correctly predicted, while 15 and 11 were predicted as "neutral" and "positive", respectively. It can be concluded that classes with a high support value (amount of class data) tend to have a higher f1-score compared to other classes.

```
Accuracy 0.6221719457013575

                         precision    recall  f1-score   support

               Aesthetic      0.53      0.54      0.54       151
               Extrinsic      0.50      0.50      0.50         2
Performance and quality      0.72      0.71      0.71       269
              Usefulness      0.10      0.10      0.10        20

                accuracy                          0.62       442
               macro avg      0.46      0.46      0.46       442
            weighted avg      0.63      0.62      0.62       442
```

Fig. 6. Label classification "product design criteria" using the SVM model

```
Accuracy 0.7601809954751131

              precision    recall  f1-score   support

    Negative       0.56      0.57      0.56        61
     Neutral       0.26      0.25      0.25        56
    Positive       0.88      0.88      0.88       325

    accuracy                           0.76       442
   macro avg       0.57      0.57      0.57       442
weighted avg       0.76      0.76      0.76       442
```

Fig. 7. Label classification "sentiment of the review", the SVM model

Tab. 4. Example of review "neutral"

Review	Rating	"Product design criteria"	"Sentiment of the review"
"this is a cute top that can transition easily from summer to fall. it fits well, nice print and it's comfortable. i tried this on in the store but did not purchase it because the color washed me out. this is not the best color for a blonde. would look much better on a brunette. if this was a different color i most likely would have purchased it."	4	Aesthetic	Neutral

3.5.2. Naïve Bayes

The data training steps with the Naïve Bayes model are the same as the steps performed in the SVM model. The Naïve Bayes model is imported from the "sklearn" library. Data training is done using the "model.fit()" function from the "sklearn" library. The prediction of the "product design criteria" label using the Complement Naïve Bayes model can be seen in Fig. 8.

The accuracy obtained from the Naïve Bayes model is 50.6 %. The confusion matrix of the Naïve Bayes model for the prediction of the "product design criteria" label shows that from 269 "performance and quality" data, 152 are correctly predicted. Furthermore, the prediction of the Complement Naïve Bayes model for the label "sentiment of the review" can be seen in Fig. 9.

From the results of the classification of the label "sentiment of the review" by the Complement Naïve Bayes model, an accuracy value of 72.3 % was obtained.

Just like the previous SVM model, the low f1-score in the "neutral" class can be caused by neutral reviews that tend to discuss positive and negative aspects of clothing.

3.5.3. Logistic Regression

The Logistic Regression model is imported from the "sklearn" library. Data training is done using the "model.fit()" function from the "sklearn" library. According to the "sklearn" documentation, the model uses Multinomial Logistic Regression if more than two classes are detected (Pedregosa et al., 2011).

Accuracy 0.5067873303167421

	precision	recall	f1-score	support
Aesthetic	0.50	0.40	0.44	151
Extrinsic	0.03	0.50	0.06	2
Performance and quality	0.73	0.57	0.64	269
Usefulness	0.14	0.55	0.22	20
accuracy			0.51	442
macro avg	0.35	0.50	0.34	442
weighted avg	0.62	0.51	0.55	442

Fig. 8. Result classification label "product design criteria", Naïve Bayes model

Accuracy 0.7239819004524887

	precision	recall	f1-score	support
Negative	0.50	0.54	0.52	61
Neutral	0.23	0.34	0.28	56
Positive	0.91	0.82	0.87	325
accuracy			0.72	442
macro avg	0.55	0.57	0.55	442
weighted avg	0.77	0.72	0.74	442

Fig. 9. Label classification "sentiment of the review", Naïve Bayes model complement

Accuracy 0.6402714932126696

	precision	recall	f1-score	support
Aesthetic	0.56	0.58	0.57	151
Extrinsic	0.17	0.50	0.25	2
Performance and quality	0.75	0.70	0.72	269
Usefulness	0.22	0.30	0.26	20
accuracy			0.64	442
macro avg	0.42	0.52	0.45	442
weighted avg	0.66	0.64	0.65	442

Fig. 10. Result of label classification "product design criteria", Logistic Regression model

```
Accuracy 0.7805429864253394

              precision    recall  f1-score   support

    Negative       0.62      0.64      0.63        61
     Neutral       0.32      0.36      0.34        56
    Positive       0.91      0.88      0.89       325

    accuracy                           0.78       442
   macro avg       0.61      0.63      0.62       442
weighted avg       0.79      0.78      0.79       442
```

Fig. 11. Model result of classification label "sentiment of the review", Logistic Regression model

The prediction of the "product design criteria" label from the Logistic Regression model can be seen in Fig. 10.

The accuracy value obtained from the Logistic Regression model is 64 %.

Predictions of the Logistic Regression model for the "sentiment of the review" label can be seen in Fig. 11.

The accuracy value obtained from the Logistic Regression model for the "sentiment of the review" label is 78 %.

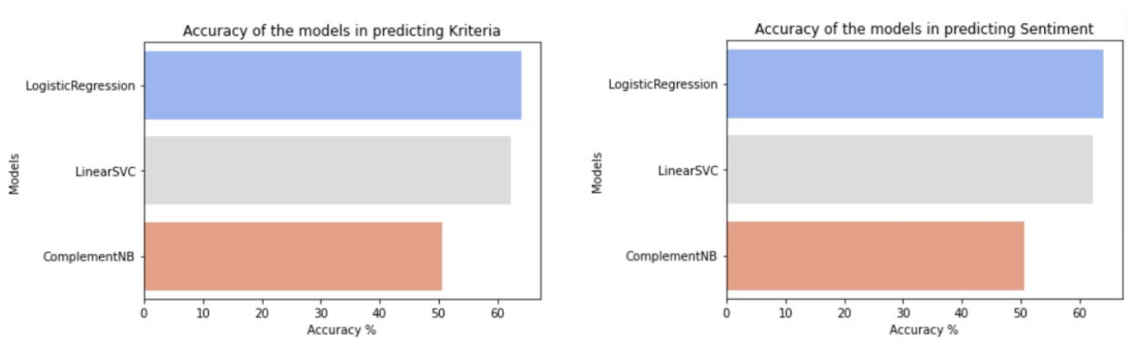
3.5.4. Comparison of classification results

After the performance of the three models is measured, the next step is to choose the best model that is going to be used to predict the "product design criteria" and "sentiment of the review" labels from the next customer review. The performance of the three models can be seen in Fig. 12.

According to Hair et al. (2014), a classification model has good accuracy if the classification accuracy value is 25 % higher than the theoretical probability. The theoretical probability of a review being classified into one of the classes on the "product design criteria" label is 25 % (one of four class choices) and 33.3 % for the "sentiment of the review" label (one of three class choices). Thus, the minimum accuracy value that must be achieved by the model for the "product design criteria" label is 31 %, and the "sentiment of the review" label is 42 %. All three models provide accurate results exceeding the minimum limit.

Based on Fig. 12 above, the model with the highest accuracy for both labels is the Logistic Regression model, with an accuracy value for the "product design criteria" label of 64 % and for the "sentiment of the review" label of 78 %. So, in this case, the Logistic Regression model was chosen as the model used to predict the labels "product design criteria" and "sentiment of the review".

As demonstrated by the three models above, the most common class grouping errors occurred in the "performance and quality" and "aesthetic" classes. This implies that the terminology used in the review of the two classes intersects. From the description of



Models	Accuracy
LogisticRegression	64.027149
LinearSVC	62.217195
ComplementNB	50.678733

Models	Accuracy
LogisticRegression	78.054299
LinearSVC	76.018100
ComplementNB	72.398190

Fig. 12. Performance of the three supervised classification technique models

Tab. 5. Example of a review of "aesthetic" and "performance and quality" criteria

Review text	Product design criteria
Cute little dress fits tts. it is a little high waisted. good length for my 5'9 height. i like the dress, i'm just not in love with it. i dont think it looks or feels cheap. it appears juts as pictured	Aesthetic
Loved the material, but i didn't really look at how long the dress was before i purchased both a large and a medium. im 5'5" and there was atleast 5" of material at my feet. the gaps in the front are much wider than they look. felt like the dress just fell flat. both were returned. im usually a large and the med fit better. 36d 30 in jeans	Performance and quality

each sub-criteria for the "performance and quality" and "aesthetic" classes, there is a possibility of similarities in the terminology used when the review is classified into the "styling" sub-criteria from the "aesthetic" criteria and the "fit" sub-criteria from the "aesthetic" criteria. "performance and quality". An example of a review of "aesthetic" and "performance and quality" criteria can be seen in Table 5.

From Table 5, the review text of the two criteria both mentions "size", but in context one review discusses appearance and the other review discusses the fit of the clothes being reviewed.

4. Result and discussion

The proposed framework presented in this paper can result in the requirement categorisation of customer needs based on "product design criteria" and "sentiment of the review" labels. The result of the requirement categorisation using the two labels is presented in Fig. 13.

The results of this classification can be used as a reference in determining the direction of product development. One such direction is to create products that can resolve or answer customer complaints about a criterion by looking at customer reviews with negative sentiments. Determining the direction of product development is hoped to reduce product development costs because it can save time for testing hypotheses and reduce the cost of design changes (cost of change) in later phases of product development (Folkestad & Johnson, 2001; Pedersen et al., 2016).

Based on Fig. 13, "performance and quality" are the criteria with the most negative sentiments. Decision makers can see the most used negative words in reviews about "performance and quality". Of the twenty words, the type of specific clothing that is most often mentioned is the type of a dress or a dress. When explored further, it is found that most of the words related to a dress are related to its size or fit.

Based on customer reviews about a dress presented in Table 6, negative responses regarding the "performance and quality" criteria of the dress are the

0	I love the color of this dress. it is not flat...	Aesthetic	Negative
1	I received the vest and it was pretty much as ...	Aesthetic	Neutral
2	This dress is really beautiful, cheerful, the ...	Aesthetic	Neutral
3	I'll admit that i often believe you pay for th...	Performance and quality	Positive
4	I recently purchased this dress in the yellow,...	Aesthetic	Positive
...	...	...	...
12469	I was surprised at the positive reviews for th...	Aesthetic	Negative
12470	So i wasn't sure about ordering this skirt bec...	Aesthetic	Positive
12471	I was very happy to snag this dress at such a ...	Extrinsic	Negative
12472	This fit well, but the top was very see throug...	Performance and quality	Positive
12473	I bought this dress for a wedding i have this ...	Performance and quality	Neutral

Fig. 13. Result of requirement categorisation steps based on "product design criteria" and "sentiment of the review" labels

Tab. 6. Example of review of "aesthetic" criteria; "performance and quality"

Just piping in here -- ordered my usual size of small petite. the slip that came with the dress is about a size negative zero, it could hardly squeeze over my body and the dress itself is a bright pale aqua and it is a shift. and because of the smocking it hangs very strangely. i think it looks very cheap and is ill fitting. i would say if you are a person on which shift dresses look awesome you might like this, but mind the size of the slip in the petites range, and also it is aqua.
I'm a fan of yumi kim dresses and consistently wear size small. so, i ordered this in a small, and the top was a little loose, but it was way too short. there's no way i would feel comfortable wearing this in public. i'm 5'7", and the hem was higher than mid-thigh on me. the waist is also billowy and has no defined shape.
This is a pretty dress. i bought a size 0 and the body of the dress fit, however, the sleeves were too long. had to return, as the loose and longer sleeves made the dress look too big on me.
I was really excited to receive this dress. it's a fun concept and different from anything else i have. however, the dress was way too short on me. i'm 5 ft 6 in., and the size medium was way too short. given the thin nature of the material, i did not feel comfortable keeping the dress, even for wearing it outside the office. i will have to return this dress.
Ordered this dress in an xs, that is the size i usually wear. this runs small, but not only that it is the way it is cut, very small through the hips, thighs and legs. hard to walk in it. the material felt kind of cheap to me. i thought it looked really good on the model, but got it home and didn't like it at all! it went back!
This dress looks cute online, but it is enormous. i bought a small, but it looked more like a 3x plus size. i tried it on, just in case, and honestly it looked like a great dress for a clown. this dress must have had two feet of fabric pinned behind the model in the photo.

discrepancy between the clothing sizes listed and the actual clothing sizes.

Thus, decision-makers can determine the direction of product development of dresses with sizes that suit most customers' body sizes. In addition, the framework proposed in the research presented in this paper can improve the process of product development, especially during the conceptual stage.

Based on the results of the case study in Section 3, the proposed framework can fill the gaps presented by Shabestari et al. (2019). The first contribution is that the proposed framework can show the success of using supervised learning techniques in the initial stages of product development, where the use of supervised learning techniques for classification is said to be better than unsupervised learning techniques (Abad et al., 2017; Edwards et al., 2021). The second contribution is that in the case study, a comparison was made of the three classification techniques, in which, for this case, it can be concluded that the Logistic Regression technique shows better accuracy than the other two techniques.

Meanwhile, the results demonstrate that the proposed framework can produce sentiment output, which is easier to use as a basis in the product development process. This is different from other techniques, as stated by Ireland and Liu (2018), where although it is easy to obtain customer preference data using sentiment analysis techniques, it is still difficult to use the results as insights in the product development process. This proposed framework is different because of the two label kinds, "product design criteria" and "sentiment of the review", and the resulting output, which is similar to Fig. 13, of the product features can be broken down, and the VoC for these features can be raised. This way, the output of sentiment analysis can be directly applied as a basis in the product development process.

To apply the proposed framework for other types of products, it is necessary to determine product criteria and sub-criteria (product design criteria), which is similar to Table 3 in the case study above, referring to the processes and standards in the product to be developed. With adequate product design criteria, the proposed framework can obtain VoC, which facilitates the product development process.

Conclusions

Product development can generally be grouped into three major stages: conceptual design, prototyping, and product launch. Voice of Customer (VoC) is especially needed during the product development stages in the conceptual design. One way to get VoC is through customer reviews. Based on the set of data on women's clothing reviews from an e-commerce site downloaded from www.kaggle.com based on data by Agarap (2018), it can be proved (Section 3) that the proposed framework (Fig. 1) can be applied. The steps of the product development process, especially in the requirement categorisation stage, can be performed using the framework presented in this research, i.e., data labelling, data pre-processing, feature extraction, and classification. The research presented in this paper used a supervised multilabel classification technique of Logistic Regression. The framework proposed in this study can also be used in general for all types of products if the product criteria are well-defined and can be used to label customer reviews. In addition, the research presented in this paper also answers one of the concerns in the categorisation of needs raised by Shabestari et al. (2019), namely, the unclear rules or main attributes of a requirement that make these needs fall into certain categories.

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Knowledge transfer in interim management projects

Beata Skowron-Mielnik
Grzegorz Sobiecki

ABSTRACT
This study aims to define the role of knowledge in a triad of factors determining effectiveness in Interim Management (IM) projects. The discussion is based on the authors' research concept, which, in addition to knowledge, also explores the categories of trust and power. A longitudinal study using the empirical-inductive approach was conducted in Poland between 2019 and 2021. It included ten enterprises that implemented IM projects in the studied period. The results presented in this article confirm the importance of the empirically adopted study factors, including the transfer of knowledge between the Interim Manager and the client's (organisation's) project team. A significant relationship between the level of knowledge and the levels of trust and power emerges as particularly evident. Research can be continued to verify the authors' initial findings and include the proposed research tools and entities representing different sectors, management cultures and geographical regions in search of additional variables and their correlations with trust, power and knowledge. The research conclusions may prove applicable to both Interim Managers (IMs) and their clients (organisations). They can be used not only for pre-project planning but also during the IM projects.

KEY WORDS
knowledge transfer, interim management, power, trust

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Beata Skowron-Mielnik

Poznań University of Economics and Business, Poland
ORCID 0000-0001-9285-0413

Corresponding author:
e-mail: beata.mielnik@ue.poznan.pl

Grzegorz Sobiecki

BMPS Consulting, Poland
ORCID 0000-0002-7875-6153

Introduction

Interim Management (IM) can be defined as a temporary provision of management resources and skills, whereby a verified executive manager is assigned to short-term manage a transition, a crisis or a change in the organisation. IM aims to ensure external managerial staff who is responsible for the IM project — a temporary internal activity with a predefined purpose and scope aimed at achieving specific and sustainable business results (Faber & Till, 2015, pp. 3–9; Metodyka..., 2014, p. 1; Şenturan,

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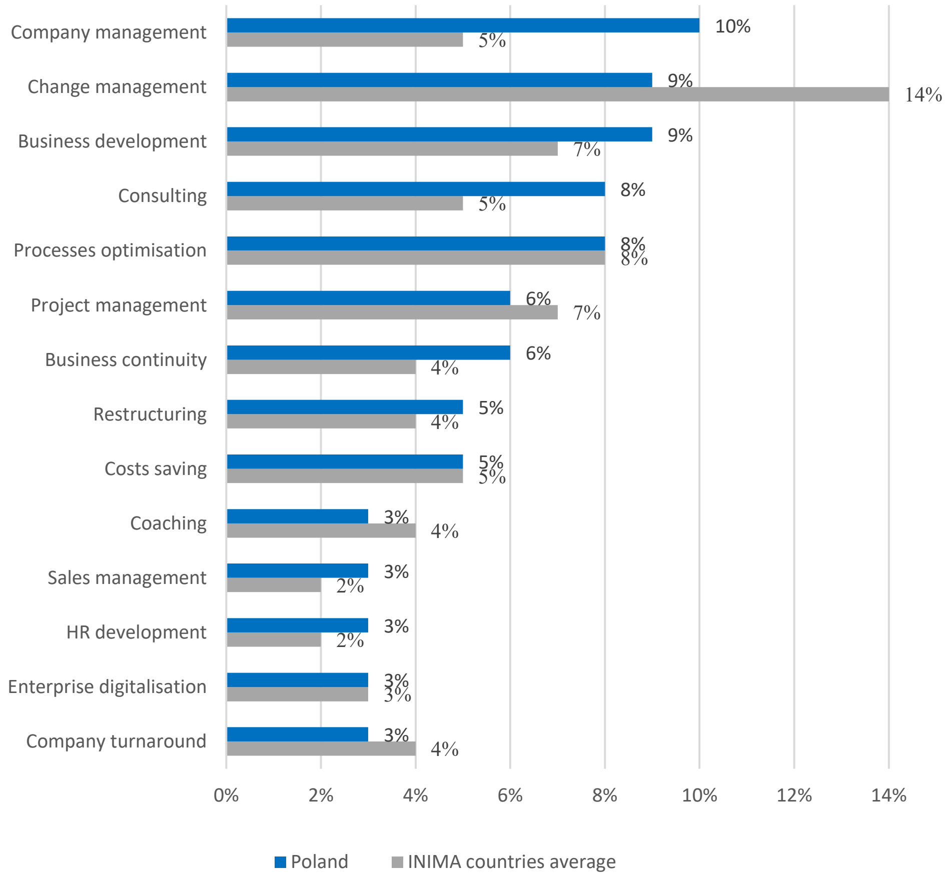

Fig. 1. Business issues managed by Interim Managers in their last project

Source: INIMA (2021).

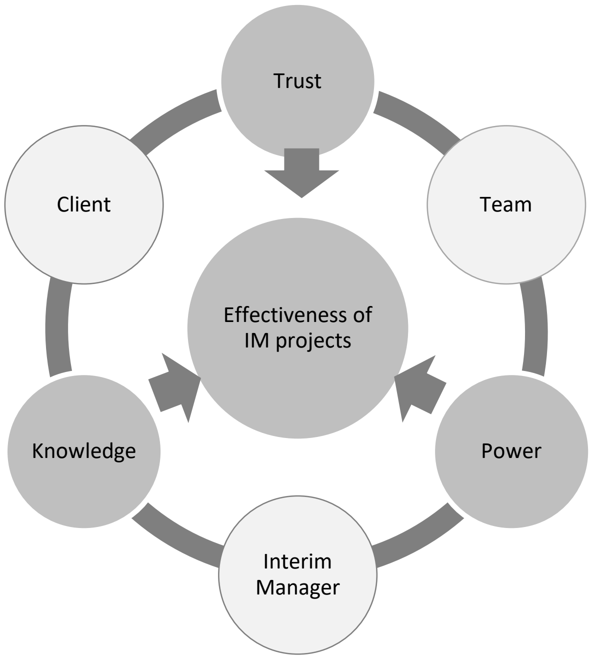

Fig. 2. Research model: three categories of factors and three stakeholders

Source: (Skowron-Mielnik & Sobiecki, 2020).

2018). Interim Management typically relies on flexible working models. Interim Managers (IMs) are highly specialised management experts employed for a specific purpose and a limited period, using various forms of employment from fixed-term work arrangements to self-employment (Eurofound, 2020, pp. 51–52; Inkson & Heising, 2001, pp. 259–284; Isidor et al., 2014; Maritsa, 2021). Employers use IMs to solve short-term problems without the need to take on a long-term employment commitment (Bach, 2015). Interim Managers are predominantly people who opt for this career path, having gained experience in top management positions, i.e., management or supervisory boards. It is a formula that guarantees more flexibility for both parties: IMs can build their professional careers while organisations can work out human resources (HR) strategies that are effective for them (Russam, 2005; Urbaniec, 2022).

Among the reasons why organisations turn to IMs for support are the transformation of the operational model, company growth and, principally, change management, which indicates what types of competencies are missing, both in business and in non-profit organisations using the IM services (Buchenau, 2019; Lang, 2020; Van Hout et al., 2020). They were identified based on research conducted in nine European countries (Fig. 1): Poland, France, the United Kingdom (UK), Germany, Austria, Switzerland, Liechtenstein, Italy and Spain.

The significance of IM projects for the organisation, the positions IMs originate from, and the prospect of a relatively short time they have at their disposal (the average duration of an IM project is 11 months; International Network of Interim Management Associations, INIMA, 2021), make it necessary to look into factors determining the effectiveness in IM projects. It is an important issue for clients who want to achieve organisational goals and IMs for whom success implies good references and potential future projects with the next clients. Woods et al. (2020) reviewed individual characteristics conducive to the effective preparation for and commencement of IM-related assignments, activities and outcomes during and upon leaving the project (2020). This article proposes a more holistic approach based on a research programme that combines three categories of factors determining the effectiveness of IM projects (Fig. 2): Trust, Power and Knowledge while highlighting three perspectives of analysis: (1) the perspective of the client that employs the Interim Manager; (2) the perspective of the client's team with whom the Interim Manager cooperates; and (3) the perspective of the Interim Manager.

This article focuses on the scope and methods of using Knowledge in implementing IM projects[1]. To this end, the following research questions are asked: (1) Is Knowledge a factor that can largely determine the effectiveness of IM projects? (2) How does Knowledge relate to the other two categories of factors: Trust and Power? (3) What is the impact of Knowledge from the perspective of the client, the team and the Interim Manager?

Research questions were addressed in consecutive chapters. Literature review indicates that Knowledge is indeed a subject of interest among researchers and is considered a factor in the efficiency of achieving managerial outcomes. Drawing upon the publications, the authors present a proposed knowledge transfer process. The research methodology outlines how the authors explored the suggested process from a statistical perspective, including the proposal of a research questionnaire (see Appendix). Moving on to the chapter Research results, the authors demonstrate the consistency of their study's observations with the literature and suggest the practical applicability in planning and implementing Interim Management projects. They also illustrate the relationships between Knowledge, Trust, and Authority. Discussion of the results concludes the article, indicating theoretical implications and the potential application of the research findings in the everyday practice of Interim Management for various stakeholders.

1. Literature review

Literature offers no uniform definition of knowledge as a field — perhaps because, as Hunt (2003, p.100) said, "Knowledge is a concept — like gravity. You cannot see it, but can only observe its effects".

The same author also argued, "Since knowledge, itself, cannot be directly observed, it must be inferred from observing performance on a test" (Hunt, 2003, p. 102).

[1] The remaining categories of factors and the general concept of the study are discussed in other articles by the same authors. Data can be made available on request. The authors would like to thank the CEOs of the companies that participated in the surveys, the teams implementing interim projects in these organisations, and the Interim Managers for their valuable input and time invested in this project. The authors declare no conflict of interest. Both authors contributed equally to the development and writing of this article. This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The authors' literature query for a research tool applicable to this study was based on three postulates. First, given that the study sought to establish the relationship between the categories of Trust, Power and Knowledge, as reflected in the architecture of the research model (Fig. 2), the instrument itself was expected to be related as closely as possible, to the other two elements, i.e., Power and Trust, or at least to one of them if no literature sources could be found that would cover both elements simultaneously. Second, the tool had to enable the measurement of knowledge transfer as an effect rather than a theoretical abstract. Third, the choice of the tool was motivated by its concurrence with the Interim Manager's actions.

Regarding the first postulate of the research model architecture (Fig. 2), i.e., the extent to which the elements of Trust, Power and Knowledge, or Knowledge and Trust, or Knowledge and Power were covered as a single research construct in the literature, Trust was found to be combined into one with Knowledge in a study by Hill and Lineback (2012, p. 1). These authors highlight the key role of competence in building trust already in the title of their work. They argued that "you need to know not just what to do and how to do it, but also how to get it done in the organisation and the world where you work" (Hill & Lineback, 2012, p. 1). The article identifies three elements of competence:

- Technical knowledge;
- Operational knowledge;
- Political knowledge.

Examples of situations related to using the respective elements are listed in columns A and B in Table 1. It is characteristic that the authors discuss the contextual use of these three types of knowledge. Given that the context for IMs changes intrinsically from project to project, Hill and Lineback's approach emerges as particularly interesting for developing the knowledge-oriented research tool and research questions to be covered.

Columns C and D in Table 1 propose to holistically assign the three types of knowledge labelled by Hill and Lineback to two types of trust defined by McAllister (1995), i.e., affective trust and cognitive trust (discussed in our previous publication). In the context of this study, no literary source was found where the category of Knowledge would be simultaneously related not to one but two other categories (Power and Trust).

In compliance with the second postulate regarding the research tool development, the literature query also focused on measuring knowledge transfer. The latter has gained wide coverage in recent years,

Tab. 1. Technical, operational and political knowledge and its relationships with trust

Technical, operational and political knowledge (Hill & Lineback, 2012)			Trust McAllister (1995)	
Types of knowledge	A. Assignment basics	B. Management basics	C. Affective	D. Cognitive
Technical knowledge WHAT to do?	The manager does not need to be an expert; needs to know enough to: - make decisions, - set priorities, - plan assignments	The manager needs to know enough in terms of: - planning skills, - employee performance appraisal, - delegating	–	X
Operational knowledge HOW to do it?	An example from the article: The manager may be familiar with the concept of capital budgeting but must also know how it is organised in the company: the management stages involved, who approves what, and indicators to be achieved	Technical knowledge is necessary, e.g., to pass an exam; however, even if the work is delegated to other people, the manager will need the operational knowledge to manage them effectively	X	X
Political knowledge HOW TO GET IT DONE in the organisation?	Preparation of strategic proposals Political knowledge is essential to exercising influence effectively in the specific political environment of the organisation	How to ensure approval? To obtain approval, the manager must: - Be able to justify a given strategy; - Know the decision-makers; - Include the project in a larger strategy	X	–

Source: elaborated by the author based on (Hill & Lineback, 2012; McAllister, 1995).

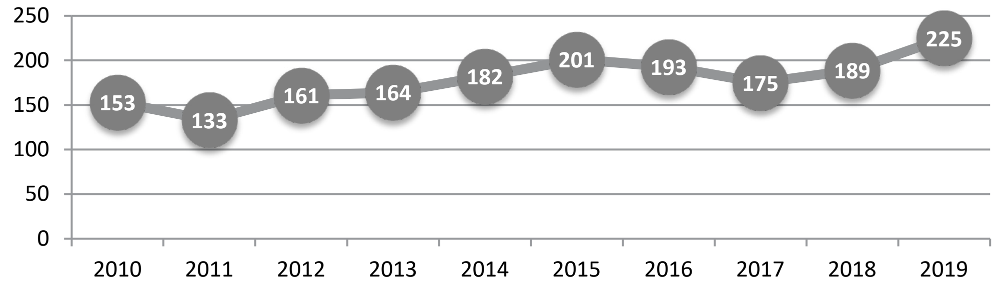

Fig. 3. Number of publications on knowledge transfer over time

Source: (Gu, Meng, & Farrukh, 2021).

which indicates the growing importance of the concept (Fig. 3). The bibliometric study by Gu et al. (2021) highlighted the evident increase in the number of publications on knowledge transfer released between 2010 and 2019, adding credence to this discussion.

This increase can be associated with a greater demand for knowledge in the daily operations of enterprises driven by new technologies and business trends. The four interpenetrating waves of technological progress coincided with the discoveries in the field of microprocessors and their progressive miniaturisation (Sobiecki, 2020), enabling the widespread use of cutting-edge solutions. The first wave, conventionally dated between 1990 and 2000, brought the emergence and then the commercial growth of the Internet. With the second wave, in early 2010, came cloud computing, and the omnipresent collection of data turned into information turned into facts for the first time connected outside the human brain (e.g., object, face, and voice recognition technology). Since then, the use of Artificial Intelligence (AI) has been growing for commercial purposes. All these changes coincide with an increasing number of publications on knowledge transfer since 2010.

Knowledge transfer is frequently discussed as part of a broader construct — knowledge management. Because of this and based on the literature review, it was proposed that the study described in this article should focus on the final phase of knowledge management, i.e., knowledge transfer, and address the entire knowledge management process. Goldoni and Oliveira (2006, p. 3) divided knowledge management processes into five stages:

- Creation — the existing knowledge is organised, and new knowledge is produced;
- Storage — knowledge is codified and then submitted to databases;
- Dissemination — knowledge is communicated or distributed within the organisation;
- Utilisation — knowledge is used;
- Measurement (results) — the effectiveness and the results of the respective knowledge management stages are evaluated.

Goldoni and Oliveira (2006, p. 3) listed sources whose description of knowledge management processes corresponds, to varying degrees, to these stages. The processes of knowledge management are presented in Table 2. Hunt (2003) argued that various authors proposed several models presenting knowledge as a non-one-dimensional construct. Table 2 appears to confirm this observation.

According to Thomas and Pretat (2009, p. 9), "a common definition [of knowledge] does not exist". Instead, they discussed it by associating such elements as data, information and knowledge. Based on this logic of the data-information-knowledge process (row 10 in Table 2), a synthesis of proposals from various authors regarding knowledge management is presented in row 11 of Table 2. Considering the third postulate for the concurrence of the research instrument with the Interim Manager's actions, the process shown in row 11 of Table 2 has been supplemented with an additional item — Teaching Adults (step F in Table 2).

The process of teaching adults is represented in the literature, e.g., by Kolb's Experiential Learning Model (ELM) and the G.I.I.A. — a four-stage model of the organisational learning cycle and experiential learning cycle for adults (Dixon, 1999, p. 65), where G.I.I.A. stands for:

- G — Generate experience: create situations at work to learn through experience and make time for it;
- I — Integrate: ensure time for the incorporation of the new experience into the old ways of working;
- I — Interpret: create opportunities/time to translate the "Integrate" stage into new working methods;

Tab. 2. Knowledge management — process stages

1. Demarest, 1997	Construction		Embodiment		Dissemination	Use			
	Management and Measurement								
2. Burk, 1999	Creation		Organisation		Sharing	Utilisation and Reutilisation			
3. Armstead, 1999	Creation				Transfer	Embedding			
	Measures								
4. Lee, Lee & Kang, 1999	Creation		Accumulation		Sharing	Utilisation	Internationalisation		
5. Ahmed, Lim & Zain, 1999	Creating				Sharing	**Measuring**	Learning and Improving		
6. Tiwana, 2002	Acquisition				Dissemination	Utilisation			
7. Darroch, 2003	Acquisition				Dissemination	Utilisation			
8. Bose, 2004	Create	Capture	Refine	Store	Disseminate				
9. Chen & Chen, 2005	Creation	Conversion			Circulation	Completion			
10. Thomas & Pretat (2009)	Data								
			Information						
					Knowledge				
11. Proposed process	A. Creation		B. Storage		C. Dissemination	D. Utilisation		E. Results	F. Teaching Adults
	Measurement								

Source: elaborated by the author based on (Goldoni & Oliveira, 2006, p. 3; Thomas & Pretat, 2009, p. 9; Dixon, 1999, p. 65).

Tab. 3. Comparison of the literature review and the authors' research concept

Srisuksa, Wiriyapinit & Bhattarakosol		Skowron-Mielnik & Sobiecki			Srisuksa, Wiriyapinit & Bhattarakosol	Skowron-Mielnik & Sobiecki			1998	1998	2000	2000	2003	2003	2004	2006	2007	2008	2008	2009	2009	2011	2011	2015	2015	2016	2020	2020	2021		
Factors affecting only knowledge transfer (nine components)		Factors of effectiveness of interim project			Knowledge transfer stakeholders	Interim project stakeholders			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Number of publications per single factor	Percentage of all 25 publications
		Knowledge	Power	Trust		Interim manager	Client	Team	Davenport & Prusak, 1998	Quinn et al., 1998	Argote & Ingram, 2000	Osterloh & Frey, 2000	Sarker et al., 2003	Reagans & McEvily, 2003	Simonin, 2004	Zarinpoush & Gotlib Conn, 2006	Eskerod & Skriver, 2007	Lockett et al., 2008	Ajmal & Koskinen, 2008	Liyanage et al., 2009	Porrawatpreyakorn et al., 2009	Ali et al., 2011	Al-Gharibeh, 2011	Karlsen & Gottschalk, 2015	Zhao et al., 2015	Bellini et al., 2016	Ibidunni et al., 2020	Bacon et al., 2020	Glaser et al., 2021		
1	Competency and knowledge transfer level	Teaching adults	–	–	Messenger	Interim manager	–	–	1	0	0	0	1	0	0	1	0	0	0	1	1	1	0	1	1	0	1	0	1	10	48%
2	Motivation and intention to transfer knowledge	Dissemi-nation	Power	Trust					0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	6	29%
3	Clear knowledge detail, clustering, and context	Storage	–	–					0	0	0	0	0	0	1	1	0	1	0	0	0	1	1	0	1	0	0	1	0	7	33%
4	Absorptive capacity level	Teaching adults	–	–	Recipient	–	Client	Team	1	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	1	8	38%
5	Motivation and intention to receive knowledge	–	Power	Trust					0	0	0	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	1	6	29%
6	Trust in messenger	–	–	Trust					0	0	0	0	0	1	0	1	0	1	0	0	1	1	0	0	1	1	1	1	1	10	48%
7	Similarities of messenger's and recipient's culture	–	–	Trust	Environment	–	Client	Team	0	1	0	0	1	0	0	0	1	0	1	1	0	0	1	1	0	0	0	1	0	8	38%
8	Knowledge transfer technology level	Teaching adults	–	–					0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	4	19%
9	Open communication level	Dissemi-nation	–	–					0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	4	19%
Number of factors (1-9) per publication									2	1	2	2	4	1	3	5	1	5	1	6	6	4	3	2	4	2	2	3	4	–	
Percentage of all nine factors affecting only knowledge (transfer as discovered by Srisuksa, Wiriyapinit & Bhattarakosol)									22%	11%	22%	22%	44%	11%	33%	56%	11%	56%	11%	67%	67%	44%	33%	22%	44%	22%	22%	33%	44%		

Source: elaborated by the author based on (Srisuksa et al., 2021; Skowron-Mielnik & Sobiecki, 2020).

- A — Act: apply new knowledge in practice and return to the first stage.

This concept was confirmed in a study by Srisuksa et al. (2021), who reviewed worldwide publications and included 63 of them in the analysis intended to "identify factors from the literature that influence knowledge transfer among (interim) projects at all levels" (Srisuksa et al., 2021, p. 211). In Table 3, the model resulting from this review is juxtaposed with the factors of effectiveness (Trust, Power and Knowledge) and project stakeholders (clients, teams, IMs) based on this research concept (Skowron-Mielnik & Sobiecki, 2020). It leads to the following findings. While the research constructs, as well as the factors and stakeholders, appear to be largely consistent for both models, comparing their distribution across the principal 25 publications and the nine factors affecting knowledge transfer requires further analysis. This finding becomes evident when Table 3 is read like a map of scattered research projects. The bottom row of Table 3 indicates that none of the 25 publications (listed in the top row covers all nine factors influencing knowledge transfer, with a coverage ratio of 67 % found only in two cases. The last column specifies the percentage of publications that refer to the nine factors. It never exceeds 50 %, and in most cases it is lower than 30 %. Considering the chronology of the analysed sources, since 2009, a growing increase can be observed in the number of publications recognising the nine components of knowledge transfer (the bottom row in Table 3).

As a result, it was established that the research tool for the study of Knowledge should have the following characteristics:

- It should focus on effect measurement rather than theory.
- The effect to be measured should be knowledge transfer through Kolb's learning cycle and the G.I.I.A. cycle, and more broadly, through process.

The tool should be based on the Likert scale questionnaire results with questions intended to reveal the use of both learning cycles in the client's organisation — learning and the incorporation of new work methods (effect).

2. Research methodology

The empirical part of this study originated from grounded theory, where hypotheses are based on the analysis of empirical data, with the theory emerging from systematically conducted field research (Oktay,

Tab. 4. Description of IM projects included in the study

Project	Functional area	Duration	Result – type	Result vs. objective	Respondents (IM – Interim Manager)	Research tool	
#1	IT / IT	6 months	Implementation of the IT system	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–
#2	Logistics / Rail vehicle repairs	12 months	Implementation of a logistics management system	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	–	–
#3	Production / Mobile device repairs	5 months	Technology transfer	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–
#4	Finance / Consulting	6 months	Implementation of a financial reporting system	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–
#5	Operational / Construction	8 months	Improved ability and effectiveness of contract performance	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–
#6	Operational / Sales in retail stores	6 months	Process improvement	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–

#7	HR / Surface treatment and anti-corrosion coating	12 months	Replacement for the duration of the planned leave	N/A	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–
#8	Finance / Surface treatment and anti-corrosion coating	6 months	Covering the vacancy until a full-time employee could be hired permanently	N/A	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–
#9	Operational, furniture industry	6 months	Improved effectiveness of managers' work	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–
#10	Purchasing, construction industry	8 months	Improved effectiveness of the purchasing processes	Achieved 100 %	Client	Questionnaire	Interview
					IM	–	Interview
					Team	Questionnaire	–

2012). This research programme required repeated surveys of interim projects implemented in actual business organisations to determine to what extent the use of IM solutions influenced project effectiveness, defined as meeting the organisation's needs. The study included 10 IM projects (Table 4). An important condition that affected the study implementation time was that all enrolled projects had to be completed (finished at the final stage of our research at the latest), which was expected to guarantee a relative objectiveness of all respondents (clients, IMs and teams) when assessing the projects. All surveys were conducted in the period between 2019 and 2021.

The study was carried out in two stages. First, surveys were conducted among IMs, their clients and the teams managed by IMs. To this end, a specially designed questionnaire was used with 30 questions divided into six groups of five questions each. The groups corresponded to the six stages of the knowledge management process. Appendix 1 presents the coded questionnaire (the key to the questionnaire can be obtained at the written request of the interested parties).

Second, after collecting and analysing the questionnaires from the clients and teams in all companies listed in Table 4, interviews were conducted with the clients and IMs in the respective companies to portray a more complete picture of knowledge and its importance in implementing IM projects. The anonymity principle was applied to all organisations and respondents to avoid response bias.

3. Research results

The survey obtained high scores for all three categories of factors (Trust, Power and Knowledge). Based on descriptive statistics, the category of Trust was found to have the highest score, corresponding to the median value for the "Strongly agree" responses, and was followed by Power and Knowledge, for which the score was the lowest (Fig. 4). The high scores confirm the correct selection of the categories of factors determining effectiveness in IM projects adopted in this research. At the same time, it allows for the conclusion that very high levels of Trust are essential to obtain a relatively high level of Knowledge (and thus ensure the effect and the project's sustainability).

Two of the six elements analysed in the category of Knowledge proved to be of the greatest importance for project effectiveness: (Knowledge) Dissemination and Teaching Adults (Fig. 5). The scores for both were equivalent to the "Agree" responses, indicating that the sharing of knowledge by the Interim Manager plays a fundamental role. These elements were then followed by (Knowledge) Storage and Results (of Knowledge Use), both of which were evaluated at the level equivalent to the "Rather agree" responses.

A comparison of the scores for two categories of entities — clients and teams — reveals differences in the perception of the Interim Manager's knowledge and its importance for the effectiveness of IM projects (Figs. 6 and 7).

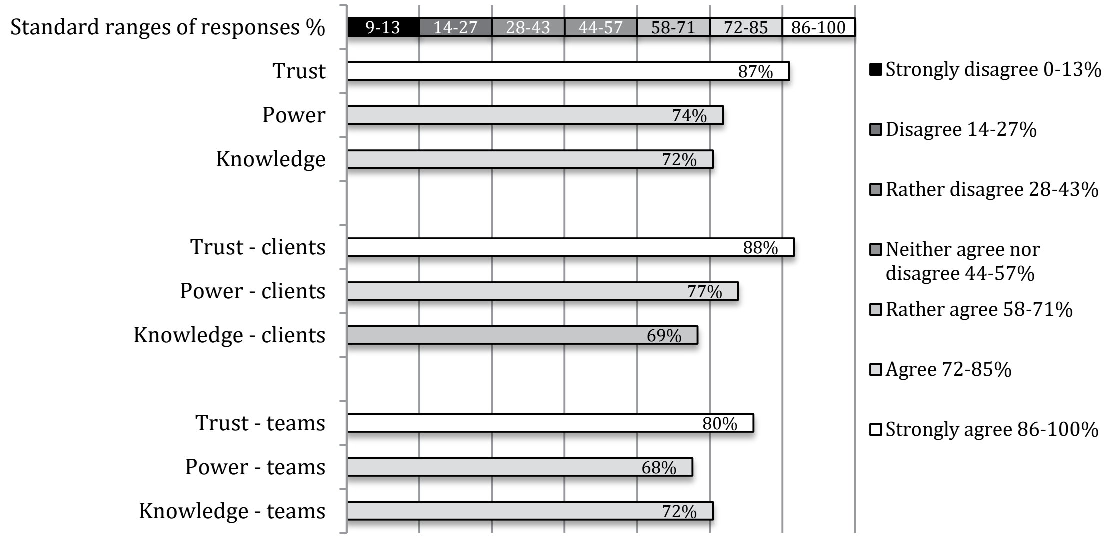

Fig. 4. Importance of effectiveness factors (median values — clients and teams altogether)

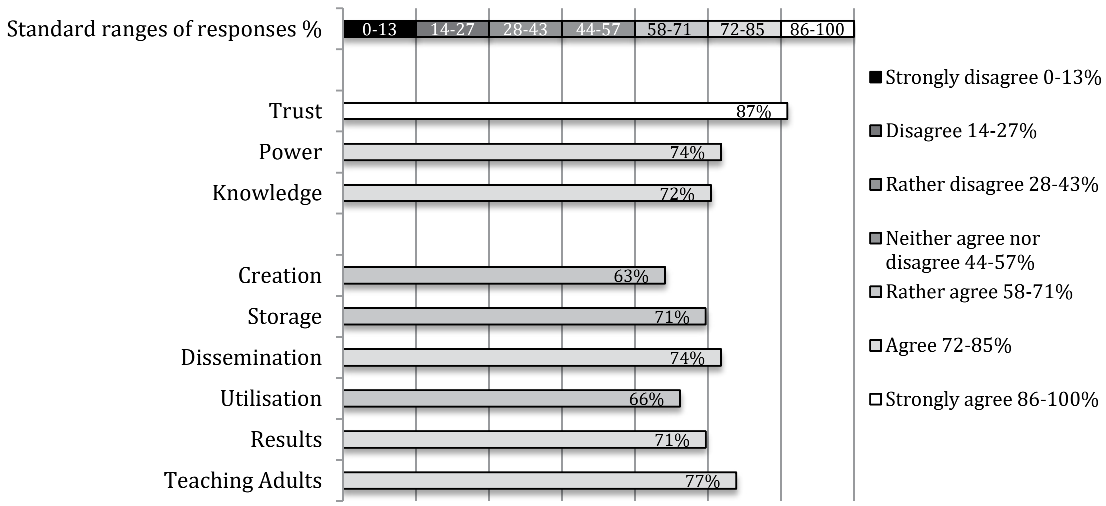

Fig. 5. Importance of Knowledge components (median values — clients and teams)

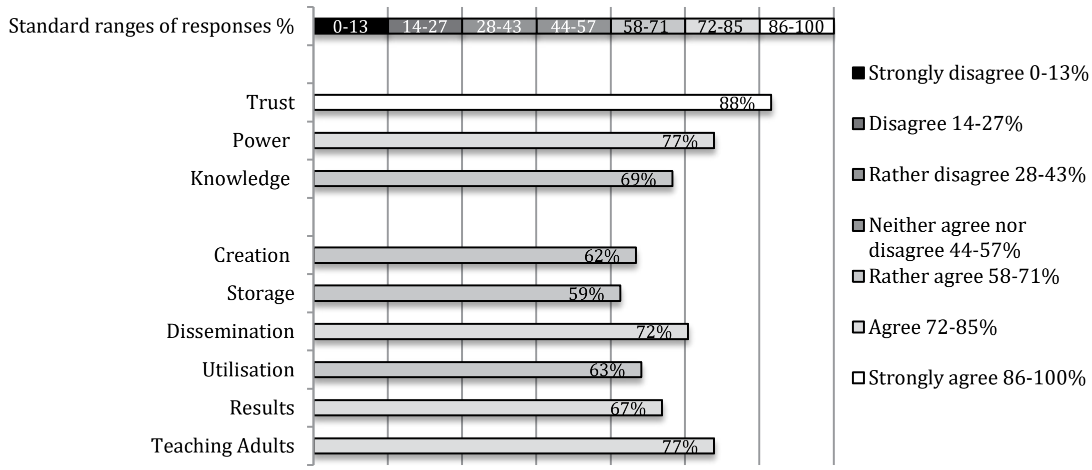

Fig. 6. Importance of Knowledge components (clients)

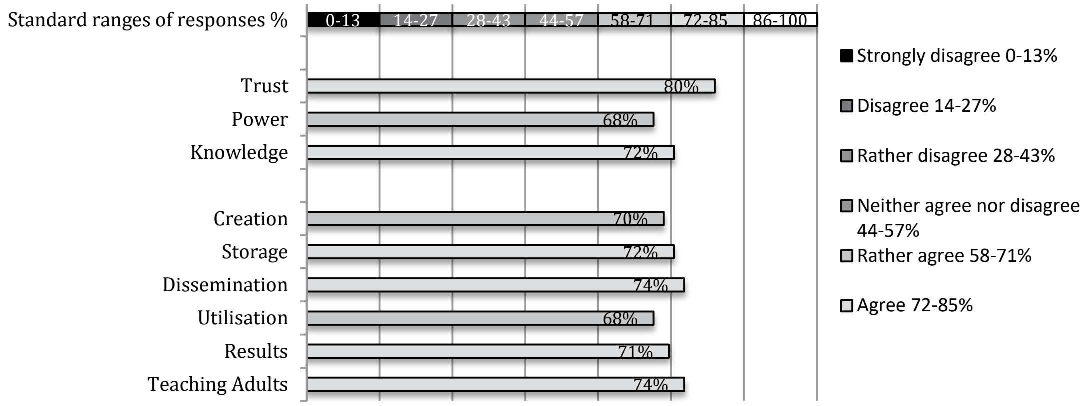

Fig. 7. Importance of Knowledge components (teams)

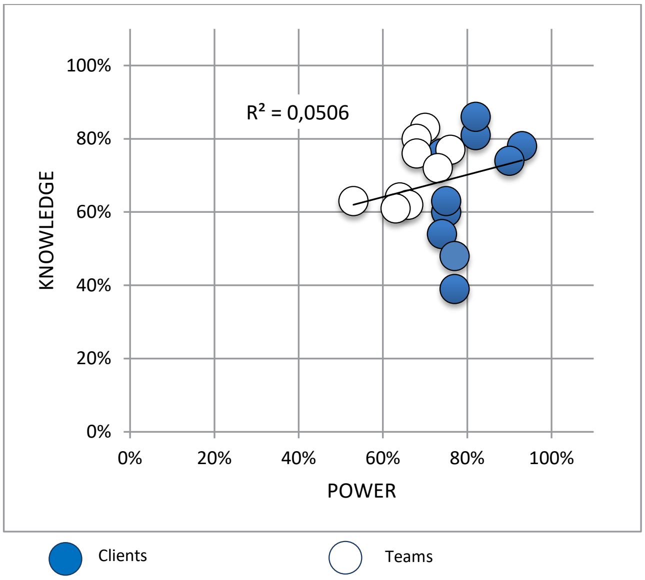

Fig. 8. Relationship between the levels of Knowledge and Power (clients and teams)

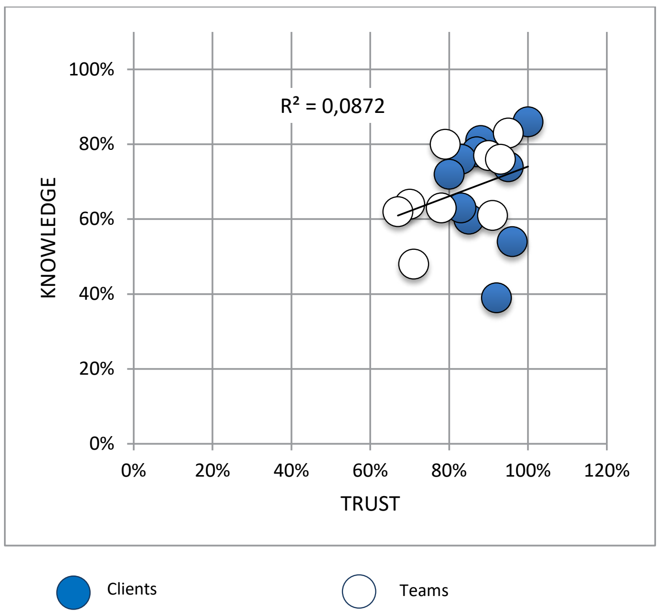

Fig. 9. Relationship between the levels of Trust and Knowledge (clients and teams)

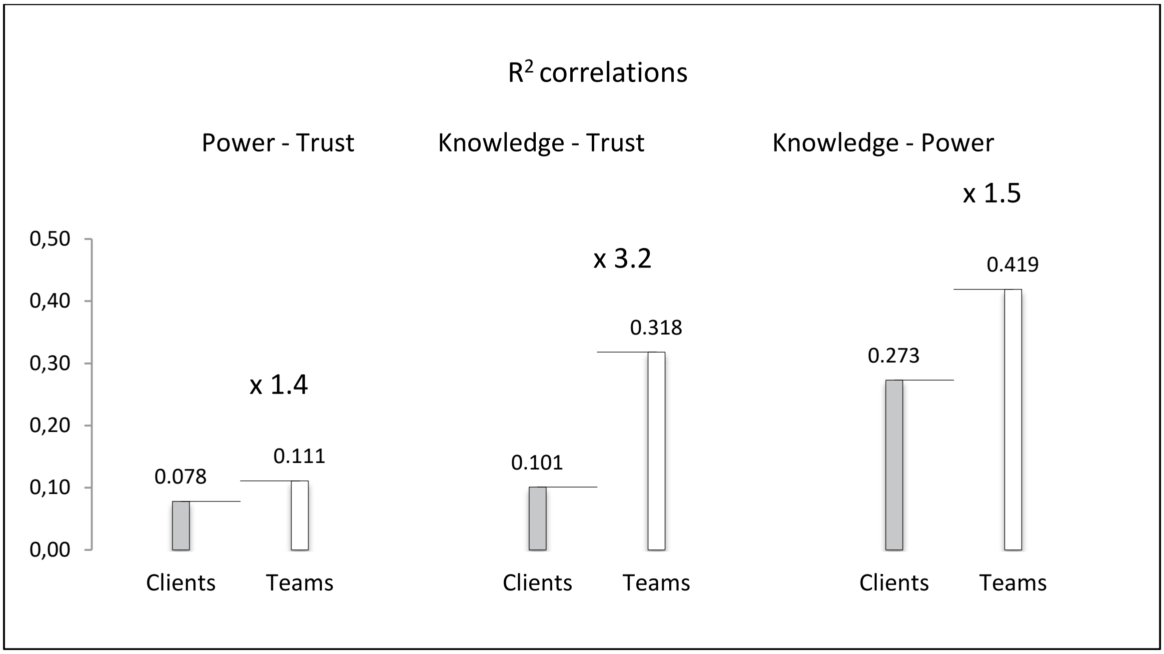

Fig. 10. Correlations between the categories of factors

The score for Knowledge among clients was equivalent to the median values for the "Rather agree" responses, with two factors emerging as the most important for effectiveness, i.e., Adult Teaching and (Knowledge) Dissemination, both assessed at the level equivalent to the "Agree" responses. In contrast, the score for (Knowledge) Storage proved to be the lowest, ranking within the lower range of the "Rather agree" responses or slightly higher but still within the same range as (Knowledge) Creation, Utilisation and Results. The low score for Creation and Utilisation among clients could imply a lesser focus on the "operational" elements of knowledge transfer in favour of performance monitoring. This would indicate their lower awareness of the Interim Manager's contribution to (Knowledge) Creation and Utilisation.

Regarding the scores for Knowledge among teams, descriptive statistics revealed a disturbance in the pattern observed among clients. While Trust also emerged as the highest-ranking category among teams, it was followed by Knowledge and then by Power. The score for the latter (Power) proved to be equivalent to the median values for the "Rather agree" responses, while that for Knowledge corresponded to the median values for the "Agree" responses. In the category of Knowledge, three of its components seem to be the most important for ensuring effectiveness: (Knowledge) Storage, Dissemination and Teaching Adults. All three were assessed at the level equivalent to the "Agree" responses. The remaining components — (Knowledge) Creation, Utilisation and Results — corresponded to the "Rather agree" responses. While the scores among teams proved similar to those among clients, a clearly smaller data dispersion (variability) was observed in the former population compared to the latter. Figs. 8 and 9 present the distribution of the correlation test results for the individual IM projects[2].

Fig. 10 presents an additional comparison of correlation values, different for the populations of clients and teams. The strength of the relationship between Power and Trust was found to be similar for both populations, i.e., the greater the trust, the higher the power levels.

In summary, it can be noted that knowledge significantly impacts the effectiveness of projects, and this observation is particularly evident in the case of teams. Therefore, it seems vital for the Interim Manager to gain the team's trust in a short time and incorporate into the client's organisation the experience in teaching adults obtained thus far.

4. Discussion of the results

Based on the comparison of the study results from two perspectives (clients and teams) and across

[2] The chart is based on the data from all ten projects. However, as no feedback could be obtained from the team in Project No. 2, the total number of scores from teams presented in the chart is nine.

three categories of factors determining effectiveness in IM projects (Table 6), it can be noted that lower levels of Trust in teams (80 % vs. 88 % among clients) were also related to lower levels of Power in teams (68 % vs. 72 % among clients), while the scores for Knowledge were higher in teams (72 %) than among clients (68 %). Therefore, Trust and Power appear to be more significant for clients commissioning an interim project, while teams working directly with the Interim Manager find Knowledge more important.

In terms of Power and Trust, clients who trust IMs more than teams do (field A.1) tend to also give IMs more power (field A.2). Guided by this approach, clients complement it with another perspective and focus during the implementation not so much on the initial phases of the knowledge management process (fields A.I – A.III) as on the effects, i.e., Knowledge Dissemination (field A.III) and Teaching Adults (field A.VI). In contrast, teams — where trust levels, while also high, are lower than among clients (field B.1) — tend to adopt a different approach to power when cooperating with IMs. A broader discussion of the five types of power analysed in our research, i.e., coercive power, reward power, legitimate power, expert power and referent power, is beyond the purview of this article. However, the results of the authors' previous studies (Skowron-Mielnik & Sobiecki, 2021) imply a significant preference for IMs to use expert power (an option marked by 80 % of respondents) and referent power (77 %) together with legitimate power (77 %) over the use of reward power (68 %) or coercive power (69 %). By leading the IM project team through the power types listed above and managing knowledge transfer processes (fields B.I – B.VI in Table 5), the Interim Manager can obtain effects from the team that will ensure similar levels of scores for all elements of knowledge management in the team.

Considering different ways of working with the client or the team and the Interim Manager's stronger or weaker focus on these perspectives, the median values for the category of Knowledge among clients and teams are similar (respectively, 69 % and 72 %; field A.3 in Table 6). This observation may suggest the applicability of the author's conclusions in planning a selective approach to each project by the Interim Manager and the client while paying attention to other general relationships revealed in the research.

Descriptive statistics in Fig. 11 show that trust towards IMs in the studied projects was assessed comparably high both among clients and teams (respectively, 88 % and 80 %), which corresponds to the majority of respondents marking the "Strongly agree" and "Agree" options. In most projects, clients assessed the importance of Trust higher than teams. A positive relationship can also be noticed between the levels of Trust and Power; however, clients and teams differed in their assessments of what determines effectiveness in IM projects. The former (clients) found the power they provide to the Interim Manager more significant (77 %) compared to the latter (teams), while teams reporting to the Interim Manager pointed to a greater importance of Knowledge (72 %) compared to clients.

While the leading theme of this article is knowledge as a factor of effectiveness in IM projects, the

Tab. 5. Combined and comparative conclusions (clients and teams)

			A.	B.
		#	Clients	Teams
Categories of factors determining effectiveness — median values	Trust	1.	88%	80%
	Power	2.	77%	68%
	Knowledge	3.	69%	72%
Category of Knowledge — median values	Creation	I.	62%	70%
	Storage	II.	59%	72%
	Dissemination	III.	72%	74%
	Utilisation	IV.	63%	68%
	Results	V.	67%	71%
	Teaching Adults	VI.	77%	74%

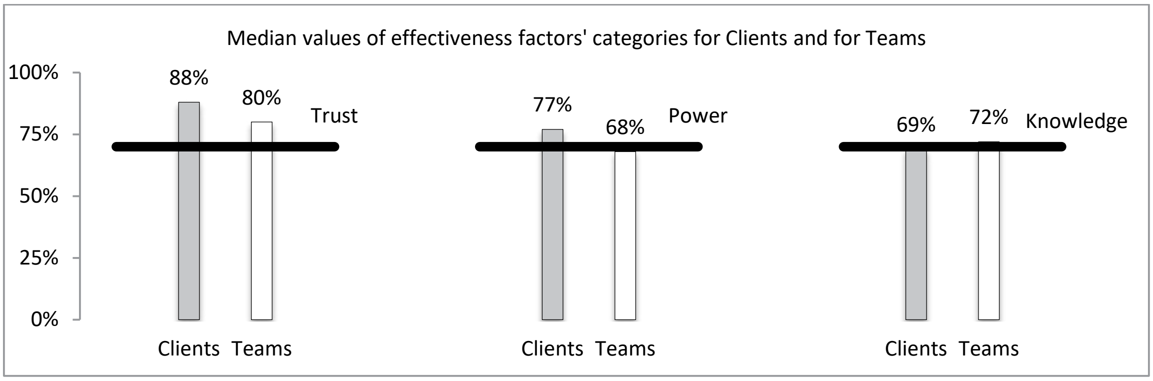

Fig. 11. Levels for the categories of factors — median values from ten projects

starting point for the research model included two more categories of factors — Trust and Power — as well as stakeholders represented by three populations: clients, teams and Interim Managers (Fig. 2). These three factors and three types of stakeholders were related by three research questions pertaining to knowledge:

1) Is knowledge a factor that can largely determine the effectiveness of IM projects?
2) How does knowledge relate to the other two categories of factors: trust and power?
3) What is the impact of knowledge from the perspective of the client, the team and the Interim Manager?

While already covered to a certain extent, academic diligence requires that clear and explicit answers be provided to these questions:

1) Regarding the first research question, the study results imply a positive answer. Based on Fig. 4, the median value of knowledge for clients and teams together was 72 %, corresponding to the "Agree" responses. Therefore, the result was statistically significant.
2) There is a clear relationship between knowledge and the other two factors of effectiveness in IM projects:
   a) The results presented in Fig. 4 indicate a cascading decrease in the median values for the three factors:
      i. Regarding Trust, the total median value for both clients and teams was the highest, and at 87 %, it corresponded to the "Strongly agree" responses.
      ii. Regarding Power, the total median value for clients and teams was lower than that of Trust, and at 74 %, it corresponded to the "Agree" responses.
      iii. Regarding Knowledge, the total median value for clients and teams was lower than that of power, and at 72 %, it corresponded to the "Agree" responses.
   b) The results presented in Fig. 5 indicate the following as the most statistically significant components of knowledge:
      i. Teaching adults (median value of 77 % — the "Agree" responses) implies a relationship with trust as a circumstance that fosters not only knowledge transfer but also its "voluntary" acquisition by the team with which the Interim Manager works. As a result, the Interim Manager can implement new and more effective practices in the organisation's daily operations or improve the effectiveness of those currently in use. Given the "voluntary" character of the process, it is conducive to self-development and, consequently, continuous improvement through an inspired rather than instrumental approach to the organisational learning cycle and individual learning.
      ii. Dissemination (median value of 74 % — the "Agree" responses) determines the broadly defined distribution of knowledge and the popularisation of the mentioned practices across the client's organisation.
3) A deeper analysis of the results aimed to study the differences in the impact of Knowledge and its relationships with Trust and Power separately for clients and teams leads to the following conclusions:
   a) The value of the coefficient of determination (R2) for Knowledge and Trust in the ten studied projects was more than three times higher for teams compared to clients (Fig. 11). This strengthens the observation made in point 2bi regarding the statistically signifi-

cant relationship between Trust and Knowledge, and its impact on the development of more effective practices through interim management.

b) For the effective implementation of the project through Knowledge transfer, the Interim Manager must gain Power over the team at a level higher than that provided to them in the client's opinion. Fig. 11 indicates that the R2 value for Knowledge and Power was one and a half times higher for teams than for clients.

Conclusions

Reverting to the previously mentioned analysis by Srisuksa et al. (2021) and the comparison of both research approaches in Table 2, it can be noticed that this deductive research based on international literature and the inductive-empirical study of ten projects led to similar conclusions about knowledge transfer. This observation could imply that the research conducted in Polish organisations is consistent with international research. The difference in favour of the empirical approach is that this study demonstrates the mutual impact of the effectiveness factors such as trust and power on knowledge (knowledge transfer). In summary, it could be argued that the research providing the foundation for this article makes a practical contribution to or at least complements research on knowledge transfer in interim projects. Therefore, the findings may be treated as a point of reference for the future continuation of research.

The surveys have been conducted on a sample of clients and teams in interim projects implemented exclusively in Poland, where Interim Management is a less known and less frequently applied concept than in Western Europe. Therefore, research conducted in countries other than Poland would certainly constitute a vital contribution to this discussion. Also, the relatively modest number of projects does not allow for the findings to refer to the nature of the participating organisations measured by factors such as company size or culture (corporations, ownership companies). Moreover, the projects included in this research thus far were largely conducted by male interim managers, which at this stage precludes a gender-based analysis of the effectiveness factors in IM projects — an aspect explored by other researchers (Kişi, 2021). Lastly, beneficiaries of this study can include not only academics but also management practitioners: Interim Managers, clients and companies that have used Interim Management for years, as well as those considering it to address their problems. The findings may prove to be particularly beneficial for employees involved in projects supervised by Interim Managers.

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APPENDIX 1. QUESTIONNAIRE FORM

RESEARCH TOOL DEDICATED TO KNOWLEDGE

Dear Respondent,

- By completing this questionnaire, you participate in scientific research on Interim Management (IM).
- The research is conducted as a joint effort of the Poznań University of Economics and Business and the Interim Managers Association (SIM) of Poland.
- As a person who has been part of an IM project, you are invited to share your valuable insight with us by answering these questions and thus contributing to the discovery of factors that may have an effect on IM projects and their outcomes.

Instructions for completing the questionnaire

- Please mark your answer for each question by circling a number from 1 to 7.
- Choose the number that best represents your opinion regarding the issue asked in the question (1 – Strongly disagree, 2 – Disagree, 3 – Rather disagree, 4 – Neither agree nor disagree, 5 – Rather agree, 6 – Agree, 7 – Strongly agree).
- Choose the answers spontaneously, to the best of your knowledge.

Anonymity

- Your personal data and answers, as well as the data and answers of other respondents, will not be disclosed.
- Your answers will be statistically processed in a pool of data along with the answers from other respondents. As a result, only the aggregated observations will be published regarding the factors that, statistically, can have an impact on IM projects and their effectiveness.

No.	Questions	Answers						
1	During the project, employees receive a bonus for developing new ways to streamline their workflow	1	2	3	4	5	6	7
2	During the project, employees are informed that new ways are being developed to streamline their workflow	1	2	3	4	5	6	7
3	During the project, employees are trained in new ways to improve performance	1	2	3	4	5	6	7
4	During the project, employees receive a bonus for using new ways to improve performance	1	2	3	4	5	6	7
5	During the project, employees receive tasks related to the implementation of new ways to streamline workflow in their department	1	2	3	4	5	6	7
6	During the project, employees can independently try out new ways to streamline their workflow	1	2	3	4	5	6	7
7	During the project, employees develop new ways to streamline the workflow in their departments	1	2	3	4	5	6	7
8	As part of the project, a database is created of new ways to streamline our workflow	1	2	3	4	5	6	7
9	During the project, employees are informed what knowledge, where or from whom they can obtain at different levels of the organisation	1	2	3	4	5	6	7
10	During the project, employees are shown how to use new ways to streamline the workflow	1	2	3	4	5	6	7
11	During the project, money is allocated to implement new ways to streamline the workflow	1	2	3	4	5	6	7
12	During the project, employees are allowed to make mistakes when trying to implement new ways to streamline the workflow	1	2	3	4	5	6	7

13	During the project, employees create new ways to streamline their workflow together with colleagues from related departments	1	2	3	4	5	6	7
14	During the project, employees are informed how they can independently access the database of ways to streamline the workflow	1	2	3	4	5	6	7
15	During the project, employees share knowledge with colleagues in their department, which encourages them to adopt the same attitude	1	2	3	4	5	6	7
16	During the project, employees use new ways to improve performance invented by colleagues from related departments	1	2	3	4	5	6	7
17	The implementation of new ways to streamline the workflow in our department brings measurable effects	1	2	3	4	5	6	7
18	During the project, employees are asked to share their opinions regarding the implementation of new ways to streamline the workflow	1	2	3	4	5	6	7
19	During the project, employees are given assistance in developing new ways to streamline their workflow	1	2	3	4	5	6	7
20	During the project, employees can independently add to the database their own ways to streamline the workflow	1	2	3	4	5	6	7
21	During the project, employees recognise the acquired knowledge as the common good of the organisation rather than an element of personal advantage	1	2	3	4	5	6	7
22	During the project, employees receive clear communication on how to use new ways to streamline the workflow	1	2	3	4	5	6	7
23	The implementation of new ways to streamline the workflow between related departments brings measurable effects	1	2	3	4	5	6	7
24	During the project, employees are given assistance in implementing new ways to streamline the workflow	1	2	3	4	5	6	7
25	During the project, all employee ideas, even the small ones, are approached with an open mind and respect in order to check whether they can be implemented and thus streamline the workflow	1	2	3	4	5	6	7
26	During the project, employees learn new names for new ways of streamlining the workflow	1	2	3	4	5	6	7
27	During the project, employees share new ways to streamline the workflow with colleagues from other departments	1	2	3	4	5	6	7
28	During the project, employees are given assistance at their workplace in implementing new ways to streamline the workflow	1	2	3	4	5	6	7
29	During the project, employees receive tasks to carry out together with colleagues from other departments related to the implementation of new ways to streamline the workflow	1	2	3	4	5	6	7
30	During the project, employees are informed which colleagues can help them implement new ways to improve work	1	2	3	4	5	6	7

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Performance evaluation method of the service quality dimensions using Six Sigma metrics, the main components' quality indicator and the geometric capacity indicator

Tomás José Fontalvo Herrera
Roberto Herrera Acosta
Ana Gabriela Banquez Maturana

ABSTRACT
This research aims to propose an evaluation and monitoring method with the Six Sigma performance metrics, the main component quality indicator, and the geometric capacity indicator to control service quality dimensions. The research was quantitative and evaluative. It was developed using primary historical information on the quality criteria of hotel service in twelve periods of 2019. It was possible to demonstrate that the geometric indicator was the most demanding capacity with a value of 0.91163, followed by the multivariate main components' indicator with a value of 0.9559, establishing as a relevant finding the integrality of the three performance criteria to evaluate a service. Topics of service quality, Six Sigma metrics, multivariate main component and geometric capacity indicators were addressed as a theoretical foundation. The research provides a unique contribution in the form of an innovative and efficient continuous improvement method, which makes services more reliable and accurate. Univariate and multivariate statistics were intensively used to evaluate and improve the dimensions of a service from different perspectives. This method has not been considered from the same approach despite its great usefulness in quality control.

KEY WORDS
service measurement, Six Sigma, multivariate capacity indicators

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Tomás José Fontalvo Herrera

University of Cartagena, Colombia
ORCID 0000-0003-4642-9251
Corresponding author:
e-mail:
tfontalvoh@unicartagena.edu.co

Roberto Herrera Acosta

Atlántico University, Colombia
ORCID 0000-0002-9448-1188

Ana Gabriela Banquez Maturana

University of Cartagena, Colombia
ORCID 0000-0002-8354-6396

Introduction

With the globalisation of the economy and the global pandemic, the services sector finds itself in a new context where services must be more reliable and accurate (Fontalvo et al., 2022a; Fontalvo et al., 2022b) to respond to new customer demands and new forms of interaction. Therefore, intensive use of univariate and multivariate statistics is required to evaluate and improve service dimensions from different perspectives (Bagherian et al., 2022; Barreto & Herrera, 2022; Chia, 2023; De La Hoz et al., 2023).

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This research analysed the best way to evaluate the performance of quality criteria or quality dimensions associated with service provision. As a result, it was necessary to evaluate different metrics to measure this type of economic activity through method articulation. In this sense, recent research shows the importance of using the Six Sigma methodology or its metrics to establish robust statistical criteria to generate improvements in the processes and services where they are implemented (Maged et al., 2019; Fontalvo & Banquez, 2023; Rana et al., 2018; Madhani, 2022; Najm et al., 2022; Sodhi et al., 2023). Consequently, this research seeks to establish a measurement structure that allows for evaluating quality dimensions through different metrics and multivariate quality capacity indicators associated with statistical quality control. It also compares which of these metrics allows evaluating the quality dimension's performance integrally and globally (Sharma et al., 2022; Sodhi, 2023; Banquez & Fontalvo, 2023). Recent research demonstrated the relevance of evaluating and monitoring processes from different multivariate statistical control tools. This research contributes to a deeper analysis of the quality dimensions, periodically and punctually considering nonconformity proportions. It is complemented with an analysis of two multivariate quality indicators to comprehensively assess a given service, which allows for evaluating the two proposed multivariate capacity indicators for better rigour when measuring the performance of a service from an integral perspective.

In general, this research aimed to propose a method to evaluate the performance of service quality criteria using the Six Sigma metrics, the multivariate indicator of principal components and the geometric capacity indicator. The following specific objectives were formulated: (i) evaluate service quality criteria with the Six Sigma metrics on time and periodically, (ii) evaluate the performance of service quality criteria using the multivariate indicator of the main component, (iii) evaluate the performance of service quality criteria using the multivariate geometric indicator, (iv) compare the performance evaluation of service quality criteria using the Six Sigma metrics, the multivariate indicator of the main component and the multivariate geometric indicator, (v) compare the three performance evaluation criteria for being more demanding and providing greater robustness in service measurement.

This research effort is extremely valuable for the scientific community and the service business sector as it provides a method integrating criteria for measuring service components or characteristics in a relevant way and facilitating decisions for service improvement.

1. Literature review

1.1. Six Sigma or quality metrics to measure a service

Recent studies have shown the relevance of periodically and longitudinally monitoring different service quality criteria, which allows for the identification of criteria offering improvement opportunities and excellence criteria; this facilitates action towards service improvement (De La Hoz, et al., 2020; Fontalvo et al., 2022a; Sodhi et al., 2022). It is important to note that other research addressed the Six Sigma methodology application from other perspectives, i.e., its definition, measurement, analysis, improvement, and control in service organisations, focusing more on the method's application than the Six Sigma metrics (Adhyapak et al., 2019; Belcher, 2018). However, in contrast to this study type, other research focused more on the intensive use of the Six Sigma metrics than the DMAIC methodology. They evaluated and analysed the quality criteria performance on time and in different periods, combining the Six Sigma metrics with other univariate and multivariate statistical control techniques, such as the T-square control chart and multivariate capacity indicators. This showed the relevance of articulating this tool type to monitor service delivery processes complementarily (Fontalvo & Banquez, 2023). Other authors also used multivariate control charts and main components' indicators to analyse and improve a process with normal and non-quadratic variables as traditionally addressed by multivariate control charts, specifically the T-square control chart (García et al., 2020; Aldaihani et al., 2017).

1.2. Multidimensional capacity indicators

Many authors have used Multivariate capacity indicators. Herrera (2018) consolidated different multivariate capacity indicators and showed this solution's practical utility in different companies. Other authors (Fontalvo et al., 2021) highlighted the importance of its implementation in the service sector, where this tool type is rarely applied and practically contextualised. Recent studies showed the importance of addressing process improvement with a multivariate perspective (Das et al., 2017). This is aligned with results found in other research on a multivariate approach, additionally incorporating indicators of average multivariate capacity when evaluating service provision. In other words, they monitor the process with specific metrics and use multivariate quality capacity indicators to evaluate service quality criteria globally, holistically, and multidimensionally. This provides criteria and information for better quality management decision-making to meet client criteria and their growing expectations due to new market conditions (Fontalvo & Banquez, 2023; Sreedharan et al., 2020).

When analysing the use of multivariate capacity indicators, it is important to consider different multivariate capacity indicator types proposed by other researchers (Shinde & Khadse, 2009), highlighting: (i) the type proposed by Taam, Subbaiah and Liddy (1993), Castagliola et al. (2009), Bothe (1991) and Wierda (1994); (ii) the main component capacity indicator, established by Wang and Chen (1998) and Chan, Cheng and Spiring (1988); (iii) other approaches proposed by Shahriari and Abdollahzadeh (2009) and Cumea (2013); and (iv) the parametric and non-parametric capacity indicators applying functional data indicated by Clements (1989).

1.3. Multivariate geometric capacity indicator

Process capacity indicators are numerical estimates of the process or service capacity, i.e., they give an idea of how capable the service is of meeting quality criteria, which are highly useful given that they are easy to calculate and do not have measurement units, allowing different processes to be compared. The multivariate capacity indicator for evaluating characteristics stands out among the existing capacity indicators (Chen et al., 2003). It was modified to contextualise the indicator to the present investigation and adjust it to the guidelines required in the Six Sigma methodology.

$$\mathrm{MC_p(k)} = \frac{1}{3}\emptyset^{-1}\left\{\frac{\left[\prod_{j=1}^{k} p_j\right]^{1/k}+1}{2}\right\} \tag{1}$$

This indicator measures the multivariate capacity considering the percentage of service compliance with respect to the quality criteria pj, where k can be the v criteria involved or the t periods evaluated.

1.4. Multidimensional main components' capacity indicator

The main component study is a quantitative methodology developed in 1901 by Karl Pearson, which provides information about the interdependence between analysed variables, finding their associations and reducing their number to facilitate their analysis. From this methodology, the following multivariate indicator emerges (Jackson, 1980; Wang & Du, 2000), presenting the formulations of the initial r components as follows:

$$\mathrm{MC_{PU}^{T}} = \left[\prod_{i=1}^{r}\left|\mathrm{C_{pu}}^{\mathrm{Yi}}\right|\right]^{\frac{1}{r}} \tag{2}$$

$$\mathrm{MC_{PL}^{T}} = \left[\prod_{i=1}^{r}\left|\mathrm{C_{pl}}^{\mathrm{Yi}}\right|\right]^{\frac{1}{r}} \tag{3}$$

where $\mathrm{C_{pu}}^{\mathrm{Yi}}$ y $\mathrm{C_{pl}}^{\mathrm{Yi}}$ are the values of the capacity indices for each of the main components. The calculations of the capacity indices $\mathrm{C_{pu}}$ y $\mathrm{C_{pl}}$ are defined as $\mathrm{C_{pu}} = (\mathrm{USL} - \mu)/3\sigma$ and $\mathrm{C_{pl}} = (\mu - \mathrm{lei})/3\sigma$.

Additionally, in this estimated point for each of the capacity indicators, it is necessary to perform, as a random variable, a global estimate of the criteria using confidence intervals, for which the following confidence interval is applied.

$$\widehat{\mathrm{MC}}{}_{\mathrm{PU}}^{\mathrm{T}} \pm t\alpha_{/2,n-1}\frac{s}{\sqrt{n}}, \tag{4}$$

where $s = \left[\sum_{i=1}^{r}\lambda_i\right]^{1/2}$ is an estimate of the global variability of the criteria.

2. Research methods

For the development of this research, a rational positivist analysis was carried out, aiming to propose a method that integrates different performance criteria to evaluate service quality dimensions. To do this, it was necessary to collect service-related empirical information associated with its quality criteria. In the first phase, this allowed for the determination of the defect metrics in part per million DPMO, the Sigma Z level, and the performance of the quality criteria Y. Similarly, with the empirical information of the chosen service, the performance assessment of the service quality dimensions was calculated using the multivariate main component and geometric quality capacity indicators.

As an epistemological foundation for this research, a rational conception was used to propose an evaluation method that would allow for the integration of the three statistical quality control techniques. To evaluate service quality dimensions, a comparative analysis was also performed, which implied the understanding of the complementarity between the criteria and statistical methods to evaluate the quality criteria or dimensions punctually and multidimensionally. As a principle of explanation of the study object, a combined and integral approach was used, considering different measurement criteria.

The scientific origin of this research arises from the empirical researcher's analysis when quantifying empirical information of the evaluated service's quality criteria. Therefore, the essence of science is associated with the study object, i.e., the assessment of quality criteria with univariate and multivariate statistical quality control metrics. The truth conception is related to the reality construction supported by empiricism related to the measurement of service quality criteria of this research's object. As a truth criterion, this research is based on observing, verifying, and assessing the service quality dimensions with the service's empirical information. From the above, the method's logic is inductive, supported by quantifying the numerical information of the service criteria's quality, referring to twelve analysed periods. This facilitated a rational analysis, which made integrating and comparing the three service measurement criteria possible to establish the most robust and demanding one.

To assess the quality dimensions, a hotel was selected and the quality criteria it measures were identified to compare the assessment and performance of the three metrics subject to this research when these are applied to the studied service's quality dimensions. This way, it was possible to establish the level of demand for the three quality measurement criteria. To achieve this, the quality criteria identified in the selected service company were found and are presented in Table 1.

Tab. 1. Characterisation of the selected service criteria

Quality dimension	Dimension's description	Error opportunity
Customer support	Good customer service is verified upon arrival	2
Response time	It's verified that the attention is in the planned times	2
Amiability	The customer receives cordial attention during their stay	2
Customer satisfaction	It's verified that the service provided by the hotel meets the customers' needs	2
Customer exit	The customer exit protocol complies with what was proposed	2

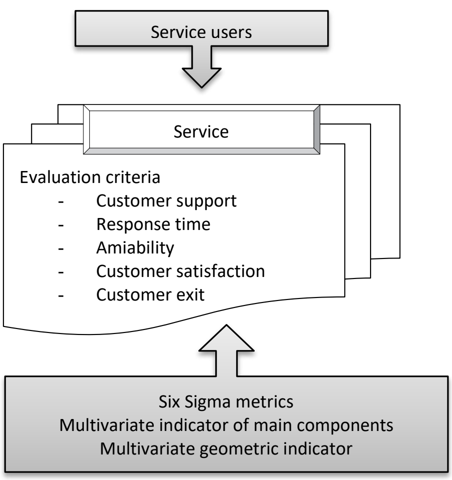

Fig. 1. Quality criteria to evaluate in the hotel service

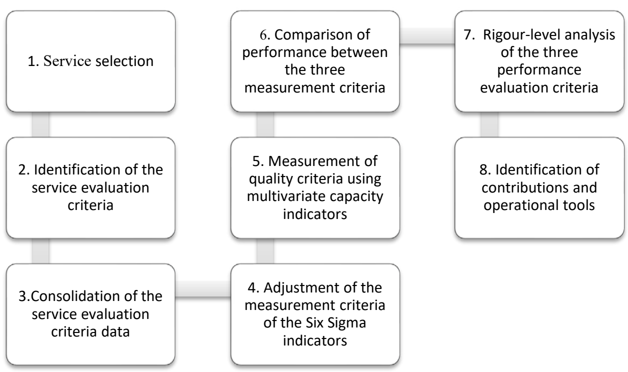

Fig. 2. Evaluation and comparison method of the service criteria performance evaluation

To develop this research, all the information was consolidated if associated with the quality dimensions established by the organisation to evaluate the service provided. Table 2 presents the information for the twelve periods of 2022. The information was used to calculate the metrics by months which allowed for the calculation of the quality capacity indicators of geometric and principal factors used.

A documentary review of the records associated with the service company's quality criteria and direct observation were carried out to collect empirical information on the quality criteria. The unstructured interview technique was used with the hotel's responsible personnel to collect information.

The consolidated empirical information of the service criteria for all the months or periods of 2019 was used to calculate the DPMO, the Sigma Z level, and the performance Y, as well as the multivariate main components and geometric capacity indicators.

Fig. 1 shows the relationship between the quality criteria and the univariate and multivariate statistical control techniques used in this research.

Fig. 2 shows the different activities of this research that support the evaluation method and comparison of the service quality criteria's performance using the Six Sigma metrics, the multivariate main components indicator and the geometric quality indicator.

3. Research results

To achieve the research objectives, the evaluation of the Six Sigma metrics of the service quality criteria was established as the first phase. In the second phase, the performance of the quality criteria was assessed using the geometric multivariate capacity indicator. In the third phase, the service quality criteria were assessed with the multivariate main component's capacity indicator, and finally, in the fourth phase, a comparative analysis of the performance evaluation of the service quality criteria was performed considering the measurement of the Six Sigma metrics and the two multivariate quality capacity indicators. This allowed for determining which of these three statistical criteria is more rigorous when evaluating quality criteria in the provision of a service.

Phase 1. Valuation of the service quality criteria using the Six Sigma metrics

Once the information related to the service quality criteria to be analysed was collected to determine which metric or capacity indicator is more rigorous, the information was consolidated on the quality criteria to be evaluated (Table 2).

Service quality results by Six Sigma

The historical information of the service company (Table 2) was then contextualised to the three measurement tools to determine the robustness and

Tab. 2. Information on service quality criteria

Quality criteria	Periods	Compliant services	Non-compliant services
Customer support	1	912	10
	2	593	13
	3	654	14
	4	638	10
	5	640	12
	6	715	9
	7	745	12
	8	662	9
	9	635	12
	10	798	9
	11	842	13
	12	976	14
Response time	1	912	12
	2	593	12
	3	654	14
	4	638	12
	5	640	11
	6	715	12
	7	745	8
	8	662	9
	9	635	8
	10	798	7
	11	842	15
	12	976	16
Amiability	1	912	10
	2	593	7
	3	654	6
	4	638	5
	5	640	9
	6	715	8
	7	745	4
	8	662	3
	9	635	4
	10	798	5
	11	842	2
	12	976	11

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Quality criteria	Periods	Compliant services	Non-compliant services
Customer satisfaction	1	912	12
	2	593	6
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	6	715	6
	7	745	3
	8	662	2
	9	635	3
	10	798	4
	11	842	2
	12	976	10
Customer exit	1	912	14
	2	593	5
	3	654	4
	4	638	3
	5	640	11
	6	715	7
	7	745	4
	8	662	3
	9	635	2
	10	798	1
	11	842	3
	12	976	4

Source: information provided by the hotel service provider.

exigency and to proceed with the calculations of the performance criteria.

Initially, the Six Sigma criteria and metrics were used to evaluate the performance of the service quality criteria with the following quantitative expressions.

U: Quantity of services provided

O: Opportunity for error

n: Number of non-compliant services

Y: Performance of the service quality dimension

DPMO: Defects Per Million Opportunities

The mathematical expressions for assessing the quality criteria performance are presented below: Defects in Parts per Million Opportunity (DPMO), the Sigma level (Z), and the performance (Y) and the equations for their calculation (4), (5), and (6).

$$\mathrm{DPMO} = \frac{n}{t} * 1.000.000 = \frac{n}{u\,x\,o} * 1.000.000 \qquad (4)$$

$$Z = \sqrt{(29.3 - 2.221 * \ln(\mathrm{DPMO}))} + 0.8406 \qquad (5)$$

$$y = 1 - \frac{n}{u * o}. \qquad (6)$$

The quantitative assessment of the quality criteria of the hotel service is presented below in Tables 3 and 4.

Tab. 3. Assessment of the Six Sigma metrics DPMO, Z and Y

Customer support			
Period	DPMO	Z	Y
1	3113.325031	4.233	99.69 %
2	1184.834123	4.535	99.88 %
3	5572.441743	4.036	99.44 %
4	6493.506494	3.983	99.35 %
5	5008.347245	4.073	99.50 %
6	3793.626707	4.167	99.62 %
7	3115.264798	4.232	99.69 %
8	7692.307692	3.922	99.23 %
9	4160.887656	4.136	99.58 %
10	2005.347594	4.374	99.80 %
11	1506.024096	4.463	99.85 %
12	2351.097179	4.323	99.76 %
Response time			
Period	DPMO	Z	Y
1	6493.506494	3.983	99.35 %
2	9917.355372	3.829	99.01 %
3	10479.04192	3.809	98.95 %
4	9230.769231	3.856	99.08 %
5	8448.540707	3.888	99.16 %
6	8253.094911	3.897	99.17 %
7	5312.084993	4.053	99.47 %
8	6706.408346	3.971	99.33 %
9	6220.839813	3.998	99.38 %
10	4347.826087	4.121	99.57 %
11	8751.458576	3.875	99.12 %
12	8064.516129	3.905	99.19 %
Amiability			
Period	DPMO	Z	Y
1	5422.993492	4.046	99.46 %
2	5833.333333	4.020	99.42 %
3	4545.454545	4.106	99.55 %
4	3888.024883	4.159	99.61 %
5	6933.744222	3.959	99.31 %
6	5532.503458	4.039	99.45 %
7	2670.226969	4.282	99.73 %
8	2255.639098	4.336	99.77 %

Tab. 3. Assessment of the Six Sigma metrics DPMO, Z and Y

Customer support			
Period	DPMO	Z	Y
8	2255.639098	4.336	99.77 %
9	3129.890454	4.231	99.69 %
10	3113.325031	4.233	99.69 %
11	1184.834123	4.535	99.88 %
12	5572.441743	4.036	99.44 %
Customer satisfaction			
Period	DPMO	Z	Y
1	6493.506494	3.983	99.35 %
2	5008.347245	4.073	99.50 %
3	3793.626707	4.167	99.62 %
4	3115.264798	4.232	99.69 %
5	7692.307692	3.922	99.23 %
6	4160.887656	4.136	99.58 %
7	2005.347594	4.374	99.80 %
8	1506.024096	4.463	99.85 %
9	2351.097179	4.323	99.76 %
10	5070.993915	4.069	99.49 %
Customer exit			
Period	DPMO	Z	Y
1	7559.395248	3.929	99.24 %
2	4180.602007	4.135	99.58 %
3	3039.513678	4.240	99.70 %
4	2340.093604	4.325	99.77 %
5	8448.540707	3.888	99.16 %
6	4847.645429	4.084	99.52 %
7	2670.226969	4.282	99.73 %
8	2255.639098	4.336	99.77 %
9	1569.858713	4.450	99.84 %
10	625.7822278	4.722	99.94 %
11	1775.147929	4.412	99.82 %
12	2040.816327	4.368	99.80 %

Table 3 shows the performance evaluation of all the quality dimensions punctually and periodically. All the specifically evaluated service dimensions show good performance in general when measured with the Six Sigma metrics.

Table 4 also shows the "average" measurement of all quality criteria or dimensions by the evaluated period, associated with the Six Sigma metrics DPMO, Z and Y. This shows the average performance per period, i.e., the service presents a good performance when the quality dimensions are measured with the Six Sigma metrics.

Tab. 4. Average performances per period

Period	Average DPMO	Average Z	Average Y
1	6278.479044	3.997	99.37 %
2	7133.142113	3.972	99.29 %
3	6467.335753	4.026	99.35 %
4	5258.04038	4.099	99.47 %
5	8145.117463	3.903	99.19 %
6	5801.920213	4.031	99.42 %
7	4116.782061	4.181	99.59 %
8	3886.023797	4.216	99.61 %
9	4509.051297	4.171	99.55 %
10	3231.381422	4.283	99.68 %
11	4099.722787	4.257	99.59 %
12	5563.895037	4.066	99.44 %

Phase 2. Assessing the performance of service quality criteria using the geometric multidimensional capacity indicator

Considering equation (1), the overall and global performance of the service's geometric multidimensional capacity indicator was assessed, which was:

$$MC_p(v) = \frac{1}{3}\emptyset^{-1}\left\{\frac{[0.9922\times\ldots\times0.9922]^{1/5}+1}{2}\right\} = 0.91163.$$

This measurement is made for each dimension for the case of customer support; the geometric multidimensional indicator for the twelve evaluated periods presents the following value,

$$MC_p(t) = \frac{1}{3}\emptyset^{-1}\left\{\frac{[0.9939\times\ldots\times0.9932]^{\frac{1}{12}}+1}{2}\right\} = 0.88647$$

The values of the capacity indicators evaluated both in the criteria and in the periods generated similar values, which implies that the variability within (intrinsic) and between (extrinsic) the criteria behaviour in the accommodation service has been homogeneous.

Phase 3. Assessing the performance of the service quality criteria using the main components' capacity indicator

Fig. 3 clearly shows that the first component is focused on the criteria of customer support and response time, and the second dimensional component focuses on the treatment given to the customer,

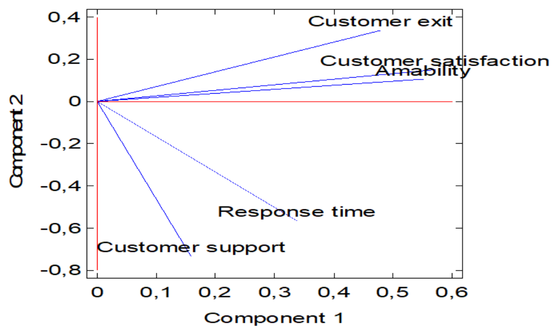

Fig. 3. Main components

Tab. 5. Eigenvalues of each of the main components

Component number	Eigenvalue	Variance percentage	Accumulated percentage
1	3.07655	51.276	51.276
2	1.55845	25.974	77.250
3	0.740425	12.340	89.590
4	0.385624	6.427	96.017
5	0.221078	3.685	99.702
6	0.0178766	0.298	100.000

Tab. 6. Main components

Quality criteria	Component 1	Component 2	Component 3
Customer support	0.157812	-0.731113	0.613679
Response time	0.337513	-0.56406	-0.753221
Amiability	0.551234	0.104538	0.158041
Customer satisfaction	0.572348	0.151477	0.167864
Customer exit	0.47931	0.336804	-0.0538652

Tab. 7. Natural specifications of each of the criteria

	Customer support	Response time	Amiability	Customer satisfaction	Customer exit
USL	10	12	10	10	10
LSL	8	7	3	2	2

Tab. 8. Comparative table of performance metrics

Quality metric	Average DPMO	Average Sigma level (Z)	Average yield (Y)	Geometric capacity indicator	PCA indicator	Confidence interval	
						Lower limit	Upper limit
Customer support	7826.44	3.92	99.22 %	0.88647	0.9559	0.4891	1.4226
Response time	7685.45	3.93	99.23 %	0.88850			
Amiability	4173.53	4.17	99.58 %	0.95488			
Customer satisfaction	3739.67	4.22	99.63 %	0.96639			
Customer exit	7756.39	3.93	99.22 %	0.88747			
Global indicator				0.91163			

in this case, amiability and satisfaction in the care of the service.

The first main component is defined as follows, standardising each of the criteria:

$$z_1 = 0.157812 \times \text{Customer support} + 0.337513 \times \times \text{Response time} + 0.551234 \times \text{Amiability} + 0.572348 \times \times \text{Customer satisfaction} + 0.47931 \times \text{Customer exit}$$

This component allows estimating the specifications of the main component's indicator based on the values specified as service quality criteria, as presented in Table 7.

Performing the linear combination calculations of the mean vector and the specification vector with the coefficients of the normalised vectors, the following results were received for the first component:

$$\text{PCA } L_{Y_1} = (8 \times 0.157812 + \cdots + 2 \times 0.47931) = 9.169$$

And the superior specification

$$U_{Y_1} = (10 \times 0.157812 + \ldots + 10 \times 0.47931) = 21.94079.$$

The result of the global capacity index is based on the main components; equations (2) and (3) present the following results:

$$MC_p^T = [1.2587 \times 0.4665 \times 1.4983]^{\frac{1}{3}} = 0.9559.$$

where the indicators of the first two components are

$$C_p^{Y_1} = \left[{|21.9407 - 9.169|}/{6 \times 1.691}\right] = 1.2587$$

$$C_p^{Y_2} = \left[{|-6.3499 - (-3.000)|}/{6 \times 1.1964}\right] = 0.4665.$$

y

$$C_p^{Y_3} = \left[{|1.21724 - (-4.3656)|}/{6 \times 0.62099}\right] = 1.49837.$$

The global value of 0.9559 of the multivariate dimensional capacity index shows a process that requires improvement. An estimate using a confidence interval is necessary, with a probability of 95 %; equation (4) presents the following results,

$$\widehat{MC}_{PU}^T \pm t_{\alpha/2,n-1}\frac{S}{\sqrt{n}} = 0.9559 \pm 2.59\frac{2.1625}{12} = [0.4891; 1.4226].$$

This is an extremely wide confidence interval. Based on the data of the periods, the index could be less than one, 0.4891 (a situation where it is necessary to make improvements in the service) or an estimated value of 1.4226, which would imply a desired situation in the service.

Phase 4. Comparative analysis of the performance of the Six Sigma metrics, the multidimensional geometric quality capacity indicator and the multidimensional main components capacity indicator.

Based on the different equations proposed in this research, all metrics and indicators of multidimensional capacity were calculated, which are presented in Table 8.

Based on Table 7 and Phases 1, 2 and 3, the multivariate geometric capacity indicator is the most robust as it presents the lowest evaluation of the service. The indicators reach the highest values.

The multivariate geometric capacity indicator presents improvement actions in the dimension of service relevance with a value of 0.91168. The global geometric indicator obtained a performance value of 0.91163. Consequently, it is more robust and demanding than the multivariate main components indicator that obtained a value of 0.9559. Table 7 shows that the least demanding indicator is the Six Sigma metrics that obtained values above 0.99 when analysing the hotel service under study in this research.

It can be asserted that the service provision is good, considering that the Six Sigma metrics, the geometric quality capacity indicator, and the multivariate main components indicator show that the performance of the quality criteria is good. In addition to empirical evidence, it can be pointed out that the geometric quality capacity indicator is the most robust and demanding, evaluating the quality of service criteria with a value of 0.911. It is followed by the multivariate main component's quality capacity indicator with a value of 0.9559, and the Six Sigma metrics, such as DPMO, Sigma level and Yield levels, with the lowest level of rigour, as shown in Table 8 for each evaluated criterion. This is a novel and significant finding as it showed other indicators being much more rigorous and useful than the Six Sigma metrics. They can be applied to assess the service quality criteria multidimensionally to measure performance and have a greater margin for improvement. That is, to the extent that the performance level obtains a lower value, service improvement actions will have to be

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Quality metric	Average DPMO	Average Sigma level (Z)	Average yield (Y)	Geometric capacity indicator	PCA indicator	Confidence interval	
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Customer exit	7756.39	3.93	99.22 %	0.88747			
Global indicator				0.91163			

taken to contribute to increasing the performance value. On the contrary, to the extent that the value of the indicator is greater, the margin or gap to improve will be less when improvement actions are taken.

4. Discussion of the results

Other investigations (Fontalvo et al., 2021) using the Six Sigma metrics and similar multicomponent quality capacity indicators have shown their relevance in measuring service quality criteria. Additionally, they show a complementary approach to monitoring and controlling a service punctually and individually with a multidimensional approach, and globally and holistically, using a different perspective for the measurement and decision-making to improve the service quality criteria (Sikder et al., 2019).

The contrasting method of using different measurement approaches has also been addressed by other researchers when monitoring processes with different multivariate statistical control tools, such as the multivariate capacity indicators proposed in this research and the multivariate control charts. This shows the relevance of the ability to identify which indicator or metric is more demanding to articulate them with the multidimensional control charts and, thus, establish more robust monitoring and control methods that guarantee decision-making for sustainable improvement of service quality (Fontalvo et al., 2022c). In contrast to this type of quality tools, Tamminen et al. (2019) also used tools to monitor quality from other quality perspectives and approaches.

Notwithstanding the quantitative findings of this research, it is important to point out that in production or service processes, when the monitored variables are presented as fractions or proportions, there are few proposals of capacity indicators for univariate fractions. This inconvenience is even greater in the multivariate field, i.e., the proportions come from p variables. It is complex to evaluate them as a whole and to evidence it in a single indicator as done and contributed by this research. Therefore, this study provides a new methodology that allows using multivariate indicators to obtain another measure to evaluate a new metric within the Six Sigma methodology that facilitates the analysis of the results of compliance proportions of different dimensions associated with a service evaluated holistically.

Conclusions

The proposed methodology shows the usefulness of articulating the Six Sigma metrics to evaluate the performance of the service on time and specifically. In addition, as another benefit, the multivariate capacity indicators allow for a holistic, integral, and global perspective, which is a benefit for those responsible for service improvement processes, considering that it allows the service quality dimensions to be evaluated independently. The multidimensional indicator of main factors allows the quality dimensions to be assessed integrally. The main factors that affect the provision of the service under study are established.

Likewise, the multivariate capacity indicator for the measurements of joint conforming proportions allows using a tool in the evaluation of fractions of conformities that occur in areas, dimensions and stages of a production or service process, which generally present different types of variables. This is an innovative contribution of this research.

As a contribution to this research work, a valuation method is proposed that integrates different criteria for measuring the quality dimensions of a service. In addition, it was possible to demonstrate that the multivariate geometric capacity indicator is much more demanding and robust to evaluate the service quality criteria when compared with the multivariate main component capacity indicator and the Six Sigma performance indicators Y, DPMO, and the Sigma Z level in the point estimates evaluated in this research. This finding is important for service organisations that require robust and demanding criteria to assess the quality criteria of a service and act for improvement according to its performance.

As a theoretical contribution, this research articulates, contrasts, and compares theories and measurement techniques of statistical control related to the Six Sigma metrics and the concept of the multivariate main component and geometric quality capacity indicators. The evidence indicates that the latter two are more demanding than the Six Sigma metrics. Likewise, the complementarity between the different indicators to measure and improve service is evident, considering the diverse approach of each measure.

As a practical and operational contribution to service measurement, it can be noted that while the

Six Sigma metrics allow the performance of the service quality criteria to be evaluated individually, punctually and periodically, the geometric and main component indicators of multivariate quality capacity allow for the evaluation of the service quality criteria multidimensionally, globally and holistically. Therefore, the two approaches can be used complementarily to monitor the service and its criteria. Therefore, the proposed method allows for having different, more robust control and monitoring criteria that affect the improvement of a service or process.

The estimation using the confidence interval shows the capacities of the service under extreme conditions; the service can obtain very low-quality indicators as well as optimal performance. In this case, it is evident that the analysed hotel service must be improved to reduce the variability of the service dimensions.

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Supply Chain 4.0: what the supply chains of the future might look like

Maciej Bielecki
Zbigniew Wisniewski
Goran Dukic
Davor Dujak

ABSTRACT
The article mainly aims to try and create a new concept for developing logistics and supply chains in the era of Industry 4.0. Analyses of development trends in logistics and production management were used to create the new logistics and supply chain concept. Conclusions were used from the analyses of how the modern concepts of Industry 4.0, Logistics 4.0, Supply Chain 4.0, and 5.0 work. Analyses of the benefits of applying modern management concepts in these areas were carried out and criticised because of their inadequacies, which became apparent during the recent crises in the world. Although the sources of the crises were different, they could be eliminated by reconfiguring logistics systems and supply chains. The results aim to answer three questions: (1) Has the time come to change the current way of looking at logistics and supply chains? (2) What could Supply Chain 4.0 look like using Industry 4.0 tools? (3) How should Supply Chain 4.0 address the logistics and supply chain challenges? The presented answers do not exhaust the topic but rather open up a discussion on logistics and supply chains of the future. The presented concept allows for a completely new global and local view of logistics chains. The structure of the presented model can be subjected to scenario analysis using agent-based simulation modelling due to the structure's emergent nature. The new approach can significantly benefit the development of local production centres and global supply networks. The benefits mainly come from reducing the environmental impact of manufacturing and logistics processes from the moment the new product idea is conceived.

KEY WORDS
Supply Chain 4.0, Industry 4.0, agent-based modelling

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Zbigniew Wisniewski

Lodz University of Technology, Poland
ORCID 0000-0003-0066-9321
Corresponding author:
e-mail: zbigniew.wisniewski@p.lodz.pl

Maciej Bielecki

University of Lodz, Poland
ORCID 0000-0001-6550-3512

Goran Dukic

University of Zagreb, Croatia
ORCID 0000-0001-8898-6756

Davor Dujak

University of Osijek, Croatia
ORCID 0000-0003-2663-8849

Introduction

Business management issues got complicated during the twenties of the 21st century to an even greater extent than in previous decades. Globalisation, mass personalisation, hyper-competition, and consumerism, referred to as chaos by Kotler and Caslione even before 2008 (Kotler & Caslione, 2009), have been made more complex by natural disasters. Natural disasters are mainly caused by an environment increasingly degraded by industry, pandemics,

Bielecki, M., Wisniewski, Z., Dukic, G., & Dujak, D. (2024). Supply Chain 4.0: what the supply chains of the future might look like. *Engineering Management in Production and Services, 16*(1), 77-92. doi: 10.2478/emj-2024-0006

armed conflicts in industrialised countries, and cyber-attacks (Chopra & Sodhi, 2004, p. 54).

Meanwhile, Germany's industrial development strategy (Industry 4.0 — I 4.0), announced in 2011, has been providing striking solutions, especially in the technological and IT spheres (Kagermann, Wahlster, & Helbig, 2013, pp. 13–15; Magruk, 2016). Cyber-physical systems, additive manufacturing, the Internet of Things, Internet of Services, augmented and virtual reality, big data, business analytics, cloud computing, etc., are opening up possibilities for organisations to create solutions limited only by human imagination (Rojko, 2017).

The development of logistics and supply chain management coincided with the development of manufacturing management. Where it was necessary to produce more efficiently, concepts such as Lean Manufacturing (Womack, Jones, & Roos, 1990) appeared, which soon received its logistical counterpart, Lean Logistics (Golsby & Martichenko, 2005, p. 65).

Where flexibility and agility had to be maintained, Agile Supply Chain concepts emerged (Towill & Christopher, 2010, p. 301), and where the broader environment had to be taken care of, Green-type concepts (Shi et al., 2012) or Corporate Social Responsibility (CSR) concepts emerged (Hopkins, 2014). Were it not for environmental changes (progressive destruction of the environment), the COVID-19 pandemic, and escalating armed conflicts in 2022 (e.g., armed conflict in Ukraine), these concepts would have developed in the industry faster, more effectively, and more efficiently.

Globalisation has made logistics and supply chains one of the most important elements of business competitiveness (Humphrey, 2003). Searching for suppliers that can offer raw materials, materials, parts, components, and finished goods has become a major challenge for many companies. When choosing purchasing sources, companies must consider such issues as cost, time, quality, and cooperation terms. Increasingly, it is also necessary to consider cultural diversity, fighting stereotypes relating to given countries or regions, operating within different time zones, and the lack of homogeneity of business ethics on a global scale (Bielecki, 2022). In addition, there are new civilisational, economic, social, and similar challenges, which include:

- dynamic and adverse environmental changes;
- new or known disruptions to economies and businesses, such as pandemics, wars, and economic crises;
- development of new Industry 4.0 technologies, including information technology finding its way into the industry;
- social changes, such as the entry of Generation Z into the labour market — iGeneration (iGen — iGeneration) — the generation of adult users of the Internet, smartphones and social media (Twenge, 2017) or the emergence of the concept of Society 5.0 — S 5.0 (Pereira, Lima, & Charrua-Santos, 2020).

All these "signs of the times" in the context of logistics and supply chains necessitate a scientific discussion on this article's topic. This discussion should address the redefinition of current business rules. The authors endeavoured to initiate a focused discussion on such a redefinition as the main research objective of this article. The result of the deliberations is to be an initiative for a new logistics and supply chain concept.

The model proposed in this article is based on a review of the issues in the literature and an analysis of the gaps identified in the referenced studies. Assumptions have been prepared from the evolution of existing logistics concepts and provide a starting point for developing a new logistics and supply chain paradigm.

The insights are also based on an analysis of the operation of actual logistics solutions. Preliminary considerations of the presented concept are included in "Total Logistics Management. Logistics and Supply Chains 4.0" (Bielecki, 2022). The article shows the conclusions of the desk research. An analysis shows interdependencies between the various subsystems, their couplings, synergy effects and other interdependencies.

Let this be an introduction to the discussion of developing a new concept. This new concept is based on the layers of customer needs, product-added value, physical flows, and digital data flows and can be, in its current version, a good start for criticism and discussion by the scientific community. This way of presenting the model may not be complete, but it will arouse curiosity.

The paper presents a literature analysis of the evolution of various supply chain concepts and their interpretation to develop the systemic, territorial and flow aspects of the concept of logistics and supply chain model 4.0. Section 3.1 is devoted to presenting the systemic aspect; Section 3.2 shows the logic of spatial operation of the logistics and supply chain model 4.0. The next section presents the key issue of the new supply chain concept of information flow.

Section 3.4 presents the determinants of the model, while Section 3.5 is devoted to presenting how to model the development of the system. An approach is proposed here that can be used to create simulation models to test various configurations of the new model.

1. Literature review — challenges of 21st-century supply chains

Negative environmental changes have continued for a long time and are not slowing down despite emerging demands and management concepts. Protecting the environment and ensuring people's right to a clean and healthy environment should be one of the priority areas of law, economics, management, and policy (Perkumienė et al., 2020, p. 2). However, regardless of existing regulatory solutions, climate change risks are growing, significantly impacting business performance (Ghadge, Wurtmann, & Seuring, 2019, p. 44). The Sustainable Development Goals set by the UN Commission on Environment and Development (2015) was one of the responses to the changes.

Some goals fit the logistics and supply chains issue, but not all. Goals directly related to supply chains include Goal 9: "industry, innovation, and infrastructure". This objective is strongly linked to logistics and supply chains. This goal, however, must be correlated with a group of intermediate goals that create specific boundaries for the development of logistics and supply chains or indicate the directions of development while emphasising its sustainability. Among the intermediate goals that logistics should consider in its development Transforming Our World: The 2030 Agenda for Sustainable Development are Goal 6: "clean water and sanitation", Goal 7: "affordable and clean energy", Goal 8: "decent work and economic growth", Goal 11: "sustainable cities and communities", and Goal 13: "climate action". Logistics development should, therefore, consider the following:

- dignity of work and wages;
- clean energy;
- minimising the impact of logistics processes on water resources by protecting them and reducing their consumption;
- minimising the negative impact of logistics processes on the climate (Bielecki, 2022, p. 15).

The new determinants of logistics development are ascertained by these goals and the overarching goal of Goal 17: "partnership for goals".

A new concept that must fit into sustainable development is that of the circular economy (CE). Kirchherr, Reike and Hekkert (2017, p. 221) collected 114 definitions of the circular economy, which were then examined in the context of 17 dimensions, which included such elements as the 4R model (4R — Reduce, Reuse, Recycle, and Recover). In their research, the authors found that the circular economy is most often portrayed as a combination of reducing, reusing and recycling. They also noted that the literature often overlooks the fact that the circular economy requires systemic change, which is an important paradigm gap. In addition, they found that definitions show few clear links between the circular economy concept and sustainable development. The CE concept itself needs to be given coherence and a framework defined so that it is not scattered by overinterpretation and extreme ideas from different authors.

When discussing sustainability and the circular economy, the issue of carbon footprint cannot be ignored. Based on a literature review, Wiedmann (2008) defined the carbon footprint as a measure of the exclusive total amount of carbon dioxide emissions that are directly and indirectly caused by an activity or as the cumulative value created over the life cycle of a product or service. The definition of carbon footprint indicates that the measure only considers carbon dioxide. However, it should be borne in mind that there are also other substances that cause the greenhouse effect, such as methane; however, there is a problem in obtaining data to calculate such a measure. In the case of having comprehensive information on the emissions of all greenhouse gases, a measure called "climate footprint" could be created. In the case of the carbon footprint, the most practical and transparent solution was chosen considering only CO2 (Wiedmann & Minx, 2008, pp. 4–5).

Until 2019, the world of logistics and supply chains was characterised by a high level of resilience to numerous disruptions. However, it should be noted that the reality of the beginning of the third decade of the 21st century is somewhat different and shows increasing uncertainty. Between 1996 and 2022, humanity has witnessed many types of unpredictable disasters, such as:

- terrorist attacks (e.g., World Trade Center and Pentagon 2001),

- wars (e.g., in Syria since 2011, in Ukraine since 2014),
- earthquakes and tsunamis (e.g., Sumatra 2012, Japan 2011, Chile 2010),
- economic crises, (e.g., USA 2009),
- pandemics (Swine flu 2009–2010, SARS-CoV-2 2020),
- strikes (examples are too numerous to cite),
- cybercrime (attack on British and Delta Airlines in 2004, attack on German steel mill in 2014),
- human errors (container ship Ever Given 2021) and others.

Tang (2007) reports that according to two independent studies, one conducted by the Centre for Research on the Epidemiology of Disasters (www.cred.be) and the other by the world's largest reinsurer, Munich Re (www.munichre.com), historical data shows that the total number of natural and artificial disasters between 1996 and 2006 increased dramatically. The average cost of these disasters has increased tenfold (Tang, 2007, p. 33) since the 1960s.

However, the COVID-19 pandemic appears to have been one of the biggest problems for logistics and supply chains in the 21st century. A Deloitte report titled Governments' Response to COVID-19 — From Pandemic Crisis to a Better Future (Eggers et al., 2020) identified three primary factors that differentiate the SARS-CoV-2 pandemic from ordinary disasters. These included:

- the development of an emergency over a long time horizon, which is in contrast to natural disasters that sometimes last seconds, minutes or hours; COVID-19 is a "slow motion" disaster that develops over weeks and months;
- COVID-19 is a global disaster, with every region of the world infected, making it impossible to move a variety of resources from unaffected locations to those affected by the pandemic (fortunately, lessons learned in one region can be applied to those regions where the virus emerged later);
- a new RNA virus (COVID-19), has a high degree of uncertainty about its timing, spread and ultimate impact; much is yet unknown, and official estimates of the virus' impact, duration and potential for recurrence vary (Eggers et al., 2020, p. 7).

This shows that global supply chains are not as resilient as they seem.

The emergence of unusual global disruptive events that slow down and hinder economic development has coincided with the development of new development concepts. Presented in Germany in 2012, the Industry 4.0 (I 4.0) concept opens up completely new horizons for logistics and supply chains (Kagermann et al., 2013). It consists of four basic concepts (Rojko, 2017), appearing most often in the literature, i.e.:

- Cyber-Physical Systems (CPS),
- Internet of Things (IoT),
- Internet of Services (IoS),
- Smart Factory (SF).

The most spectacular solution is the Smart Factory (SF) as defined by the German Research Foundation (Deutsche Forschungsgemeinschaft — DFG). It is a factory that offers previously unknown opportunities to contextually help people and machines perform their tasks (Lucke, Constantinescu, & Westkämper, 2008, pp. 115–116). Solutions proposed by I 4.0 that will affect (or are already affecting) logistics and supply chains include (Skobelev & Borovik, 2017, pp. 307–311):

- cyber-physical systems,
- virtual and augmented reality,
- artificial intelligence,
- Internet of Things, services, everything,
- big data and cloud computing,
- cyber security,
- S 5.0 operating determinants,
- evergetics.

The literature also contains attempts to combine these issues. The topic of sustainability in I 4.0 and Supply Chain 4.0 (SC 4.0) was addressed by Canas, Mula and Campuzano-Bolarin (2020, pp. 13–14). Through their research based on a literature review, they showed that most scientific work focuses mainly on enabling technologies with the overriding goal of reducing costs and increasing the effectiveness of systems control (monitoring). Thus, they concluded that there is a need to refer to a sustainable and standardised I 4.0 framework. The authors also noted that the articles often overlooked the social aspect of I 4.0.

Alicke, Rexhausen and Seyfert (2017, pp. 2–4) stated that through digitisation and new customer demands, supply chains should become

- faster; "predictive shipments" are already appearing in practice, which are shipped before a customer places an order and then matches a specific order;
- more flexible; real-time, ad hoc planning under SC 4.0 allows organisations to respond flexibly to changes in demand or supply;
- more detailed, as customers expect increasing customisation of products;
- more accurate; next-generation performance management systems provide real-time visibility across the supply chain;

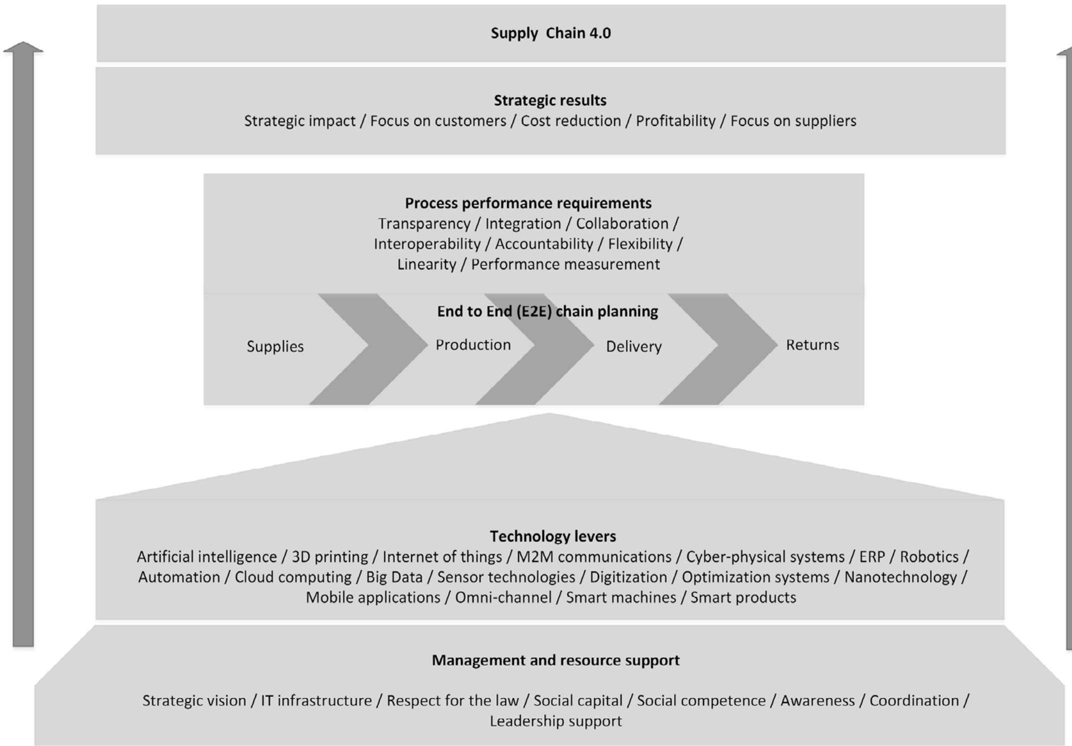

Fig. 1. Theoretical structure of the Supply Chain 4.0 concept

Source: elaborated by the author based on (Frederico, 2021, p. 18).

- more efficient; automation of physical and planning tasks increases supply chain efficiency (Alicke et al., 2017).

An interesting theoretical structure of the SC 4.0 concept was presented by Frederico, Garza-Reves, Anosike, and Kumar (2016) (Fig. 1). They based the entire concept on two basic pillars:

- management and resource support;
- technological leverage based primarily on I 4.0 solutions.

The listed elements support a phased logistics arrangement that is based on specific principles, which are requirements for process performance. All this aims to achieve strategic results that complement the SC 4.0 concept.

Although SC 4.0 is a topic on which academic work has begun, Frederico (2021, pp. 15–16) has already proposed transitioning from SC 4.0 to Supply Chain 5.0 (SC 5.0). During a systematic literature review, the author managed to identify forty-one articles related to the SC 5.0 topic. Analysis of these articles using the VOSviewer software made it possible to extract nineteen keywords forming four main conceptual constructs: industrial strategy, innovation and technology, society and sustainability, and transition issues. According to Federico, SC 5.0 encompasses an industrial strategy that seeks to create a sustainable human-technological environment and a sustainable and intelligent society. It is supported by technology and innovation, which includes I 4.0 technologies and an innovation ecosystem. The SC 5.0 strategy also involves some transitional issues arising from I 4.0 paradigms and other issues such as psychology, employee safety, social, ethical, legal and regulatory issues. The main goal of SC 5.0, in social and sustainability terms, is to create a more sustainable, intelligent society. It also creates mass personalisation of products and services in supply chains.

Based on the presented conditions and the challenges facing logistics and supply chains presented in the presented work, and considering the existing assumptions and concepts of Industry 4.0, Logistics 4.0, Supply Chain 4.0, Supply Chain 5.0, Society 5.0 in the literature, a conceptual model of logistics and Supply Chains 4.0 (L&SC 4.0) was proposed, which could become a vision of SC 4.0 dedicated especially to industrial products[1].

[1] The model's assumptions apply strictly to industrial products since the possibilities for their design and, above all, the possibilities for recovery from used finished products of materials, raw materials, and components have a much higher potential than in the case of food products, where packaging can be recovered in the main.

2. Methodology

Based on the above review of issues and the analysis of gaps identified in the referenced studies, assumptions have emerged from the evolution of existing logistics concepts and can serve as a starting point for developing a new paradigm for logistics and supply chains. The concept was prepared based on the following methods:

- literature analysis — research and analysis of scientific publications, reports, books and other literature;
- descriptive method describing the phenomenon, concept and situation without deep quantitative study;
- interpretive method focusing on understanding the meaning, significance and interpretation of social phenomena based on qualitative and conceptual data analysis;
- conceptual method analysing and developing concepts, theories, ideas, or models to enrich understanding of an issue.

A discernment of the issue was carried out based on a literature study. Then, the concepts of logistics and supply chain logistics development known and operating now and in the past were described. The conclusions became the basis for interpreting the identified concepts in the context of the changing economic environment and incidental challenges on a global scale. A posteriori knowledge of the evolution of logistics solutions in a rapidly changing environment was used.

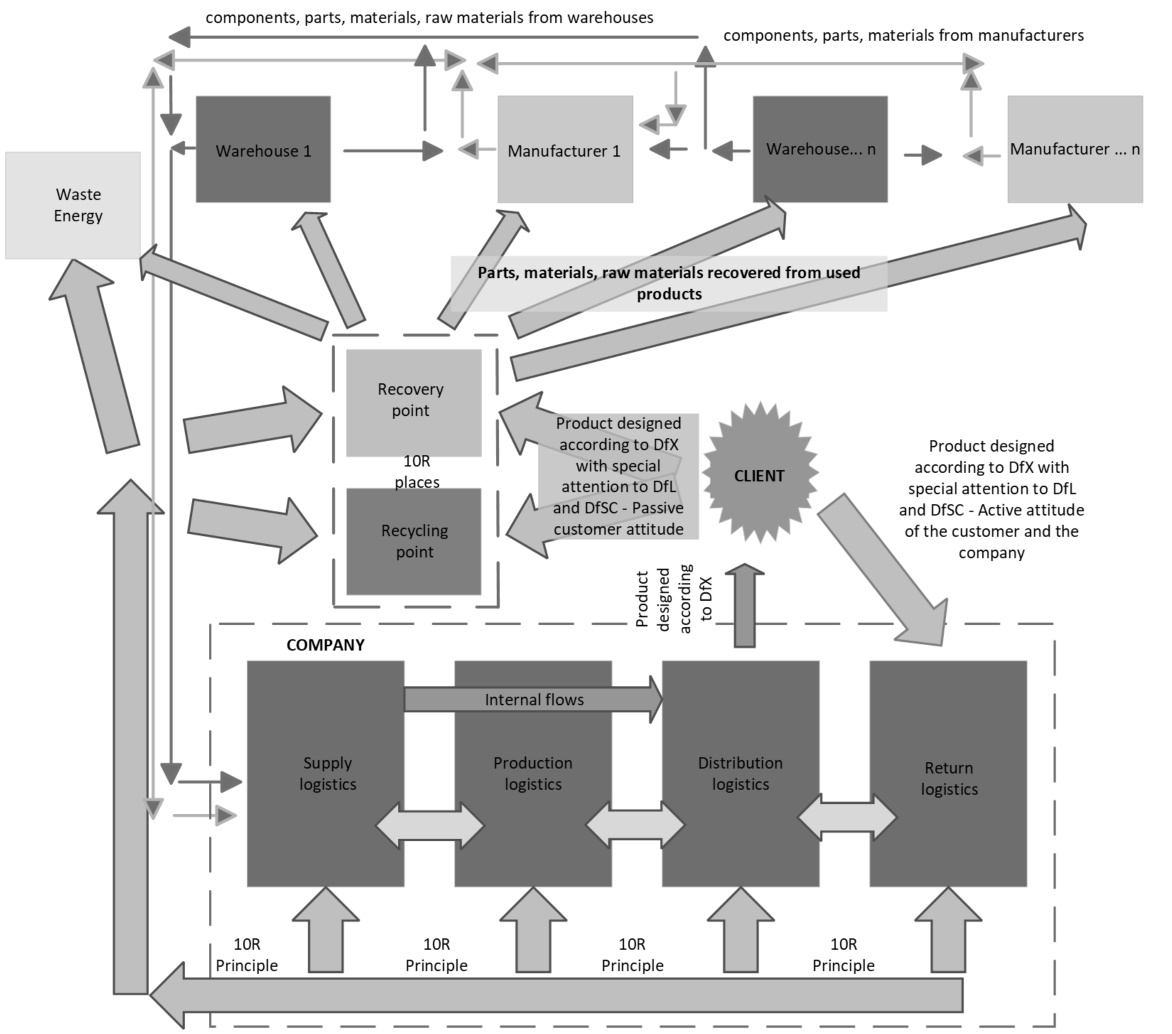

Fig. 2. Concept of collaboration among participants in the L&SC 4.0 model (the 10R Principle includes Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Re-use, Reduce, Rethink, and Refuse)

Abbreviations used: DfX — Design for Excellence, DfL — Design for Logistics, DfSC — design for Supply Chain

Source: elaborated by the author based on (Bielecki, Galińska, & Polak-Sopińska, 2021).

Following the interpretive analysis, an analysis and synthesis of the new concept of the supply chain logistics development model was performed.

3. Results and discussion — a conceptual model of Logistics and Supply Chain 4.0

The authors' proposed concept of the Logistics and Supply Chains 4.0 model will be considered from three basic aspects:

1. systemic,
2. territorial,
3. flow-based.

The flow aspect welds together the system and territory aspects; it considers physical flows (Fig. 2) and information flows (Figs. 4 and 5).

3.1. Systemic aspect

The systemic aspect distinguishes five basic types of L&SC 4.0 participants:

- customers using applications in product design and, upon approval, sending their design to the cloud based on the ERP systems of a single enterprise;
- single organisations, often single-station artisans with high specialisation using digital additive manufacturing, are served by hubs, recovery points and recycling points;
- warehouses, which are hubs where new and used raw materials, materials, parts, components and other items are available;
- recovery points that are specialised units recovering parts and components from used products, which are also warehouses for used raw materials, materials, parts and components, or transferring recovered components to specific warehouses (hubs);
- recycling points, i.e., specialised units recovering raw materials and materials from used facilities, also constituting warehouses for used raw materials, materials or transferring recovered elements to specific warehouses (hubs).

Fig. 2 presents the idea of cooperation between the participants in the conceptual L&SC 4.0 model and the aspect of physical flows. The time and routes by which the physical flow of used products is carried out depend on what attitude the customer takes towards them, i.e., passive or active. The active attitude of the customer makes it possible to give used products directly to the company, which uses the selected components in the company's internal processes in the following phases:

- distribution (e.g., packaging),
- production (e.g., screws, washers, other universal components),
- procurement (e.g., structural components).

The components of the used product that the enterprise could not use are transferred to recovery or recycling points, which put the selected components on the market.

The customer's passive attitude involves leaving used products in specially designated places, from where they can be transferred to recovery and recycling centres.

3.2. Territorial aspect

The territorial aspect demonstrates the logic of spatial functioning and cooperation among L&SC 4.0 participants. In a sense, it contradicts existing concepts of long (global) supply chains and promotes cluster solutions. These solutions can take the form of global supply chains only in extreme cases, e.g., in the absence of components recovered from the market at the company's site. This context presented in Fig. 3. is divided into five layers, which include the following spheres:

- nano: customers, individual organisations, hubs, recovery and recycling points – model participants;
- micro (micro cluster): cities, agglomerations, collections of towns and villages;
- mini (cluster): collections of several or more micro territorial units (equivalent to a province, state, and canton), cluster organisations: hubs, recovery and recycling points;
- meso: collections of provinces, a country or collection of countries (depending on their size and population), international organisations: hubs and recovery and recycling points;
- macro (global): global area, continent, world, global organisations: hubs and recovery and recycling points.

L&SC 4.0 participants and the territorial context of the system are supported by technological advances of the Fourth Industrial Revolution, which mainly include:

- extensive digitisation of products and processes;
- cyber-physical systems;

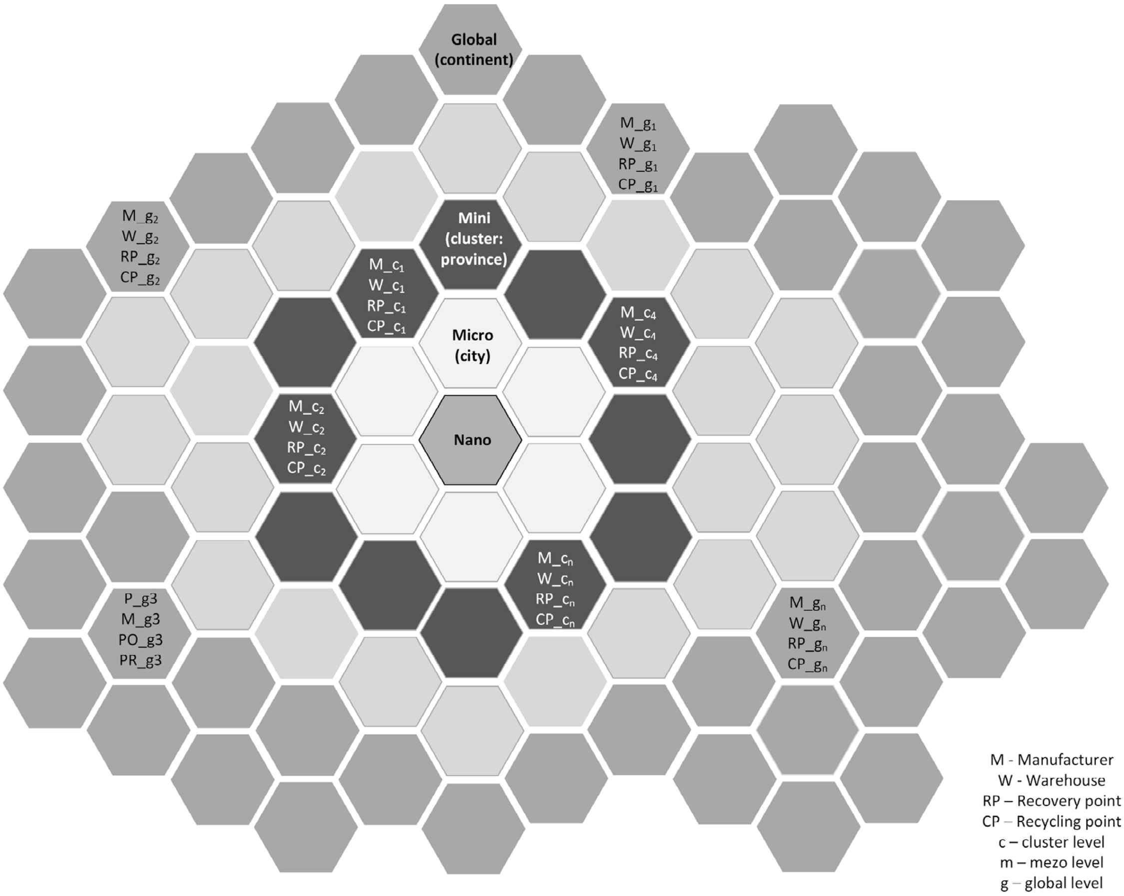

Fig. 3. Territorial structure of the L&SC 4.0 model

- applications (App) and mobile applications (MA);
- cloud computing (CC) and Big Data analytics;
- extensive Cluster Resource Planning (CRP) and ERP systems operating in enterprises;
- Forecasting and Simulation (F&S);
- Business Intelligence (BI);
- Internet of Things (IoT) with a focus on machine-to-machine (M2M) communications;
- Internet of Services (IoS);
- virtual and augmented reality;
- cyber security (CS);
- blockchain technology.

The presented layout will form a logistics system using intra-cluster cooperation on the one hand, and on the other hand, it will be open to external clusters and the meso and macro spheres. The smoothly operating intra-cluster reverse logistics of each enterprise, combined with recovery points and recycling points, allow the recovery of most of the components and parts for reuse in manufacturing processes, and the recycling points deliver recovered raw materials and materials to enterprises.

The remaining discussion focuses on the operation of the meso and global spheres, which do not differ much from the operation of the cluster. Material flows would occur within the mini-warehouses located in the cluster, which would be systematically replenished through regional, national, continental or global warehouses. In the event of changes in demand or the emergence of demand for new products, the rapidly reconfigurable warehouses would become warehouses for other than existing goods.

The meso and macro spheres are the second and subsequent warehousing hubs of L&SC 4.0. They also group manufacturers who produce their products in provinces, regions, countries, continents and globally. Distributed logistics hubs of various raw materials, materials and subassemblies or parts that, due to the nature of their production processes, cannot be produced in "artisanal factories" or clusters are supplied through Milk Run systems. These logistics trains travel the same route constantly, replenishing the same locations on a meso and macro scale. Transportation and warehousing processes are far smaller in scale than current global logistics systems. This is due to the principle of Design for Excellence (DfX), or Design for Circular Economy (DfCE). According to these concepts, most components and parts are reused to make new products.

3.3. Information flow

The key issue of the whole system becomes the sphere of information flow, i.e., digital data. Available and unified applications (home appliance and construction industries) allow customers to design and personalise their products. Once a product has been accepted by the customer and paid for to some extent through electronic flows, a bill of materials (BOM) goes to the ERP information systems of enterprises, from where it is directed to the CRP (Cluster Resource Planning) information systems in the first place. In the case of problems with the availability of materials or resources within the cluster, the CRP system shifts information about missing resources to the meso level (CRPM system — Cluster Resource Planning in the Meso Zone) or the global sphere (CRPG system — Cluster Resource Planning in the Global Zone), (Fig. 4).

The lack of resource availability at different levels necessitates their search at higher levels or involves their replenishing (if possible) at the base level. Forecasting and simulation algorithms reserve a resource by analysing its temporal and spatial availability. Based on this, feedback is returned to the company and the customer related to the timing of the order. An important aspect of this model is that the information is provided online in real time already during the customer's personalisation of the product, so they

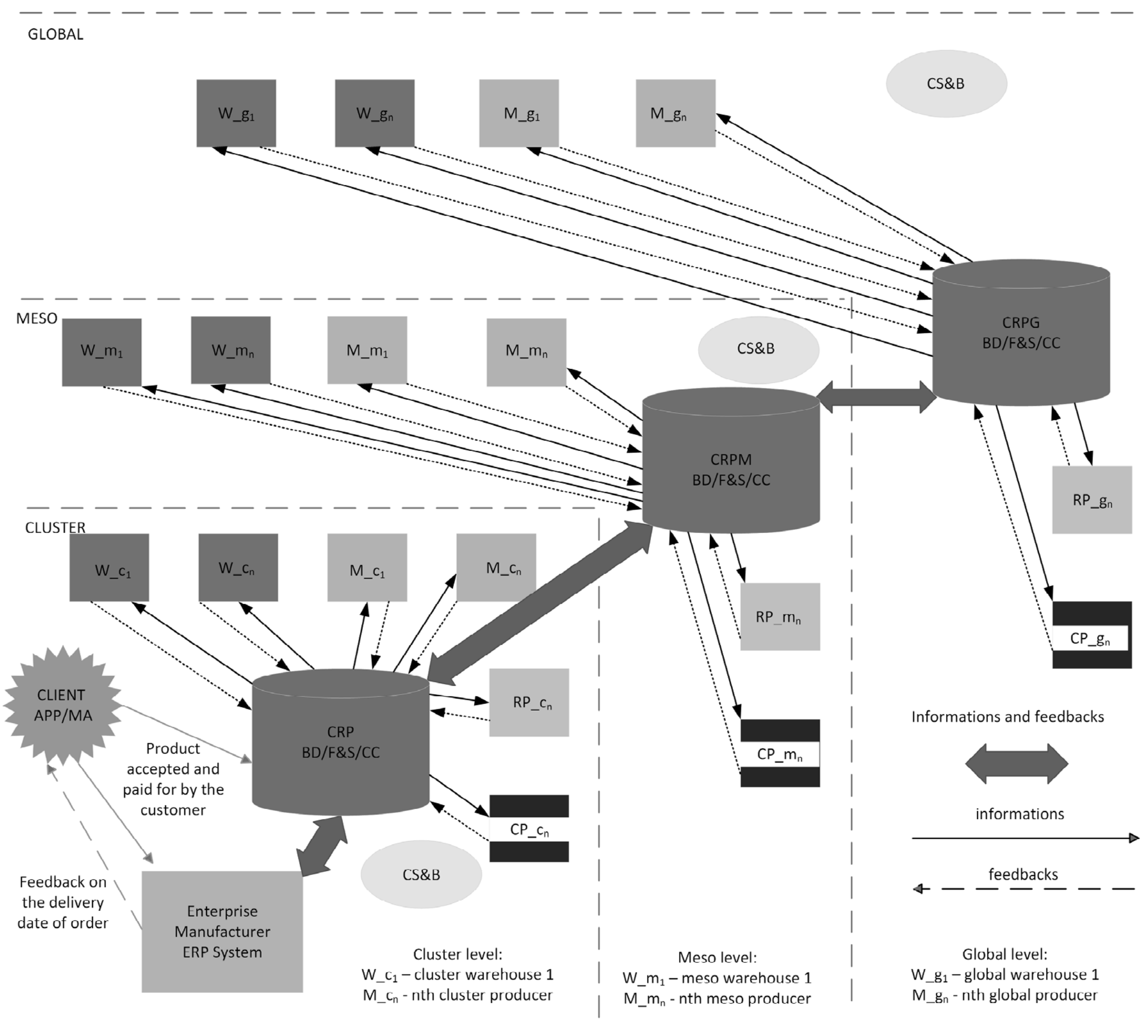

Fig. 4. Information flow between customer, organisation and cluster in the L&SC model. 4.0 — layer No.1 of the digital data flow — analysis of resource availability

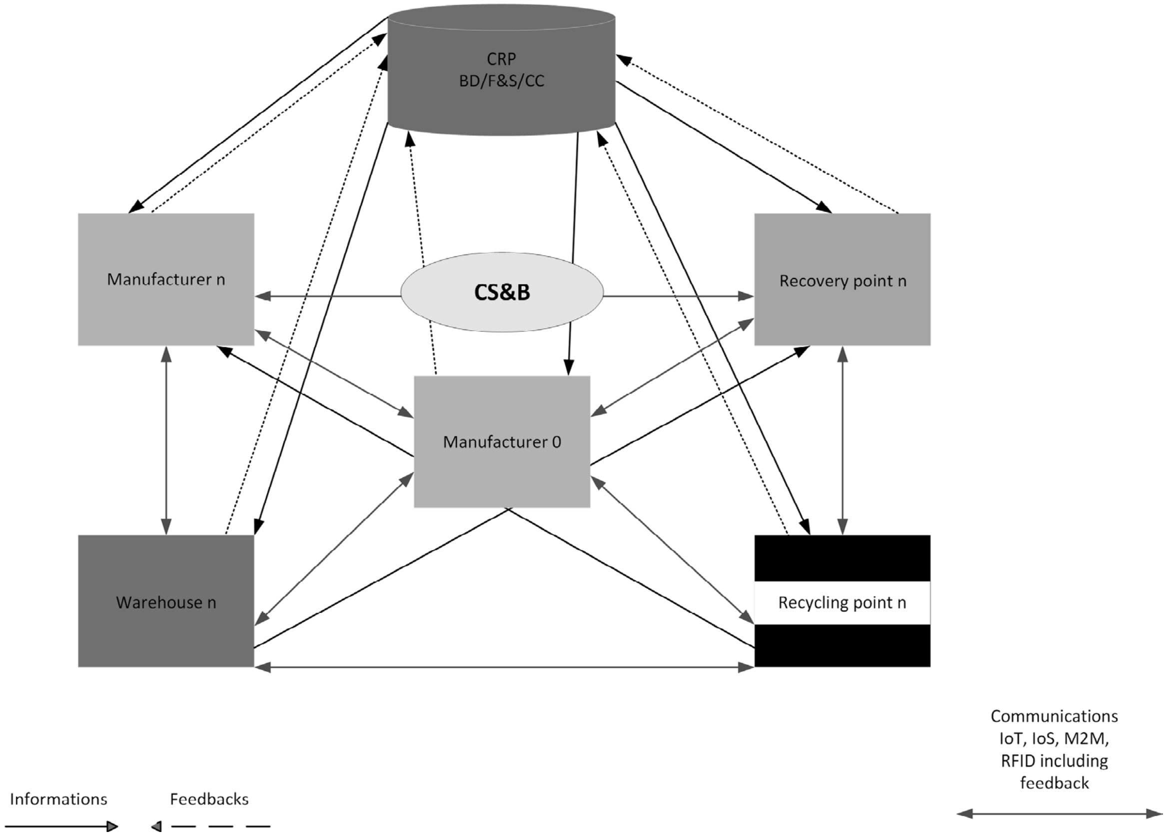

Fig. 5. Launch of manufacturing in the L&SC model. 4.0 using IoT, IoS and M2M communication technologies — Layer 2 digital data flow — launching manufacturing and physical flows

have a direct influence on the optimisation of the ordered goods in terms of the availability criterion. All this is subject to cybersecurity assurance processes while using blockchain architecture (CS&B) and other forms of Blockchain use in supply chain management (Dujak & Sajter, 2019).

The acceptance of an order with its payment or promise of payment generates the activation of cyber-physical systems (physical flow layer) in the organisations, warehouses, recovery points and recycling points included in the project implementation. Internet is used to activate technological IoS and IoT tools, generating their effects through the start of M2M communication (Fig. 5).

When all the necessary components for a product are available within the micro or mini (cluster) realm, Big Data analytics, business intelligence (BI), as well as forecasting and simulation algorithms running on cloud computing and ERP, CRP, CRPM and CRPG systems trigger M2M communications using IoT and IoS technologies. This triggers parallel processes for manufacturing or preparing necessary components. Of course, as in the previous case, the whole thing is secured by CS&B.

Necessary raw materials or materials, or manufactured spare parts go to the company, which is responsible for the final assembly of the final product. For this purpose, e.g., drones or autonomous delivery vehicles operating in tunnels located under cities can be used[2]. According to the principles of Just-in-Time and Just-in-Sequence, which form the basis of the CRP algorithms and are optimised by them, delivery of the necessary components takes place to subcontractors and the last point in the supply chain before the end customer (Fig. 2).

3.4. Determinants of the model

The presented model also assumes the existence of four basic areas influencing it, e.g.:

- customer needs and product-added value (resulting from the challenges facing logistics and sup-

[2] The second of the scenarios described by Ehrhart (2012, pp. 25–26).

ply chains and societal changes, e.g., the iGen generation entering adulthood);
- physical flows (considering the technological levers of I 4.0 — Hofmann's 4.0 model (2017, pp. 25–26);
- digital data flows (layer No. 1 — analysis of resource availability, layer No. 2 — activation of generation and physical flows) discussed above;
- necessary requirements of process operation — SC 4.0 model by Frederico, Garza-Reyes, Anosike, Kumar (2021, pp. 17–18).

The layer of customer needs and added value of the product should consider the current trends of order fulfilment showing:
- a high degree of personalisation (product customisation);
- high degree of product availability;
- fast order processing time (one click and one day — one click and day);
- use of virtual space in shopping;
- security and pragmatics of products and transactions;
- optimal price/quality ratio (Twenge, 2017, pp. 221–228);
- product compliance with the tenets of sustainability and the circular economy;
- confidence that during a crisis, the product will not run out of the market;
- use of the product for a long time with the possibility of modification — a long product lifecycle.

It should be noted that a key element of the entire model is an enterprise that uses information technology to design products and packaging that are not only logistically efficient but also incorporate several tenets of the Design for Excellence (DfX) concept. Manufacturing is not deliberately mentioned here since the enterprise's core competence becomes product design, along with managing its entire supply chain and logistics from the microsphere to the macrosphere. The sphere of product design should, therefore, consider the layer of customer needs and added value (e.g., a high degree of personalisation), but also the current standards that allow efficient and effective manufacturing or assembly, which include the following guidelines:
- a high degree of product personalisation, mainly through the realm of "software", e.g., changes in colour, functionality or other attributes that occur by activating a particular product module or incorporating optional add-ons into products;
- product designs have their application (digital) translation into programs that allow them to be designed by customers (according to the design guidelines assumed by a given company), e.g., mobile applications;
- a high degree of standardisation, modularity and multifunctionality of components resulting from careful analysis of their availability in the market;
- use of standard, intelligent materials susceptible to personalisation;
- the ability to use raw materials, supplies, spare parts, packaging and other finished product components from used finished goods and packaging subject to reverse logistics;
- accurate preparation and digitisation of technology sheets in the form of batch programs (e.g., for additive machine tools, allowing to make individual components of the finished product in a given CPS), operating instructions and service manuals.

An important model of L&SC 4.0 is product design. As a result of the thoughtful action of designers, using the concept of DfX, with special attention to DfL and DfSC, efficient reverse logistics, and inter-cluster cooperation, makes it possible to achieve closed cluster circulation. This generates little demand for raw materials, materials, and components from outside the cluster and, therefore, from the meso and global spheres.

The operation of the L&SC 4.0 model is, therefore, based on four basic phases:
1. design and analysis of resources. Based on the application or mobile applications of the enterprise in question, the customer designs their product, and at the time of acceptance, payment or generation of its promise, the enterprise with an ERP system launches the Cluster Information System (of CRP) tasked to:
   a. analyse the availability of resources within the cluster at other enterprises, hubs, recovery points and recycling points;
   b. in the absence of resource availability within the cluster, analysing resource availability at the meso and global levels;
   c. prioritisation of resources;
   d. resource reservation;
   e. estimation of lead times;
2. launch of manufacturing and physical flows, i.e., generated order of components to enterprises within the cluster or outside the cluster to the closest functioning enterprises, which, using IoT,

IoS and M2M communication technologies, can start executing orders, minimising human impact on order execution;
3. final assembly and distribution create the finished product and distribute it within the cluster using automated, autonomous transportation technologies (using IoT, IoS and M2M);
4. reverse logistics focuses on closing the product flow inside the cluster.

The presented concept of the supply chain 4.0 model still needs to be clarified, but its framework seems to provide a fairly good starting point for discussions on supply chains 4.0.

3.5. System development modelling

The concept of the L&SC 4.0 model presented in the previous chapter is somewhat complex and multilayered. The individual components that make up the relationships in this model already exist, but their configuration is novel. Developing such a complex concept and testing its effectiveness cannot be done by investing in unique solutions on a trial basis and seeing what results this will produce. This model is complex because it involves entities with an extensive territorial scope and uniquely combines entities operating in other configurations. The entire system's efficiency will depend on how effectively and efficiently processes are carried out in this new configuration.

This raises a major difficulty as the effects can only be examined after many cycles of process execution in this structure. Hence, the following questions arise: What is the probability that the proposed method of implementing logistics and supply chains will be good? What are the chances that such a model will evolve in the right direction and resist disruptions and unexpected situations? Remember that it was created as a response to problems in previous logistics and supply chain models when unexpected situations of global scope and catastrophic dimensions arose. Is it possible, then, that it will be a solution making logistics immune to large-scale disruptions? Is it possible that the model will reduce the risks of negative environmental impacts of the logistics processes themselves and the manufacturing processes to the point where the manufacturing processes and logistics processes become completely environmentally unobtrusive? Is it possible that this solution will reduce the amount of resources consumed and increase the evenness of profit allocation? Such questions can be multiplied, and many questions will be associated with each small element of such a structure.

Based on experience with the operation of logistics structures and concepts, an attempt can be made to answer such questions. The answers will concern local aspects and the current relationships between system elements. How these matters will look in a completely new configuration is unknown. Therefore, a way must be found to provide answers with an acceptably high probability of being correct. However, it must be kept in mind that once obtained, the answers are not and will never be conclusive. This is because such complex structures are dynamic and evolutionary in nature, as individual attributes and configuration relationships can change to suit current requirements and situations. Thus, it is impossible to obtain unambiguous answers that can be used as arguments for accepting or rejecting a particular solution. This is largely because the concept presented in its conception is a multi-variant solution. It is based on multiple elements, and each is described by an extensive structure of attributes, with each element related to many other objects, and together they form a system. Describing such a structure deterministically is unreasonable and inefficient, and the description would become outdated immediately after its formulation.

Modern approaches to designing highly complex structures are based not only on a deterministic approach, in which a precise description of each component at the micro-scale and all the interrelationships up to the macro scale is required. There are alternative approaches to object modelling where, due to the structures' complexity and the descriptions' mathematical complexity, it is impossible to obtain satisfactory results in an efficient time. In such cases, simulation modelling is used. It makes it possible to create a model of a given system with the accuracy determined by the adopted level of abstraction. Such a model can be extended in subsequent iterations. Simulation models make it possible to perform simulations in which both the configuration of the model and the parameters defining its operation can be changed in any way.

Simulation experiments are performed before decisions are made on the construction or expansion of individual system components. Therefore, it is proposed to create simulation models for the model structure to study how the concept works without involving real resources.

It seems that the most appropriate method for modelling the system from the perspective of its territorial structure (Fig. 3) will be the agent-based modelling method (Golroudbary et al., 2019; Hu et al., 2022). Agent-based simulation modelling (ABM) is a computational modelling technique that involves the creation of autonomous agents, representing individual entities that interact with each other and their environment to simulate real-world phenomena (Lange et al., 2021; Ruiz et al., 2011). Applications of ABM include:

- social science: to study such complex social phenomena as the emergence of norms and conventions, the spread of disease, the formation of crowds and social networks, and the dynamics of conflict and cooperation;
- economics: for modelling economic systems, such as markets and supply chains, to understand how individual components interact to determine the overall behaviour of the system;
- environmental science: to model the behaviour of complex environmental systems, such as ecosystems and climate systems;
- engineering and infrastructure: to model infrastructure systems, such as transportation networks, power grids and communication networks, to assess the impact of new policies or technological innovations;
- ABM is a powerful tool for modelling complex systems that involve a large number of interacting agents, where traditional mathematical models may be insufficient to capture system dynamics.

Therefore, it is necessary for the presented concept to undergo simulation studies and identify potential risks and develop scenarios for different conditions. The described L&SC 4.0 structures are emergent in nature, so agent-based modelling will be the most appropriate (Lange et al., 2021). Once the modes of behaviour, responses, and relationships between individual elementary objects have been designed, it will be possible to get a picture of the behaviour of the entire system and its individual components.

Conclusions

In building the L&SC 4.0 concept within the mini, meso and macro spheres, it was assumed at selected points to challenge the existing paradigms regarding the functional areas of logistics, production and quality that shape the current industry while creating additional considerations. These include:

- the logistics sphere:
  - moving away from global supply chains — maximising the shortening of supply chains to neighbourhoods, cities and county equivalents called clusters;
  - decreasing warehouse space in favour of increasing the number of small-area, quick-reconfigure warehouses — placing a large number of small warehouses of raw materials, materials, and semi-finished goods in clusters or on the border of clusters, maintaining low inventory levels for clusters; for specific raw materials, materials and parts, creating highly specialised warehouses with somewhat smaller reconfiguration capabilities;
  - creation of national warehouses for raw materials, materials and parts replenished through global traditional supply chains from which goods are delivered in an optimised manner to clusters (an element of resilient logistics to disruptions such as the COVID-19 pandemic);
  - changing the rules of reverse logistics — placing in clusters, or at the border of clusters, a large number of facilities for recovering components and raw materials from used products; creating a reverse logistics system that does not allow used products to leave the cluster in which they are located;
  - a departure from the current form of transportation — the use of underground tunnels or airways for transportation processes inside the clusters, in which autonomous "green" vehicles such as drones will move; this eliminates the negative impact of logistics processes on residents and the environment as the existing transportation is reduced to the meso and global sphere;
  - full cooperation and transparency governed by international law — cooperation among clusters in inventory management, making them available to balance supply and demand;
  - simultaneous maintenance of the concepts of Just-in-Time and Just-in-Sequence as a key element determining the effectiveness of the entire system using Milk Run systems to optimise logistics processes;

- production and quality sphere:
  - product design supporting excellence (DfX) with an emphasis on circular economy issues, quality, logistics, and manufacturing and assembly under cyber-physical systems and additive manufacturing;
  - moving away from mass production to highly personalised unit production in small "artisan" plants specialised in given technologies and operating within clusters;
  - reducing the time of making one finished product to a maximum of one day, assuming maximum use of standardisation, modularity, and multifunctionality of raw materials, materials, subassemblies and parts;
  - considering the need to use components from used products in new products — establishing a rate of used parts in the product, which would be legally changed in selected periods;
  - extending the life cycle of products by including the possibility of repairing them while improving their quality;
  - returning to the implementation of TQM principles supporting TLM, especially in the issue of synergetic cooperation of enterprises.

The presented L&SC 4.0 model seems to address many of the challenges facing today's logistics and supply chains. The arrangement of clusters globally shortens supply chains; reverse logistics makes it possible to incorporate used materials or components into re-circulation, thus closing the environmental loop while increasing the resilience of supply chains. The use of I 4.0 technologies and the principles of "green logistics" helps reduce the negative impact on the environment, while the digitisation and unification of product design processes using smart materials reduces the risk of the collapse of global supply chains.

However, it should be noted that at the present time, the presented L&SC 4.0 model has at least a few key limitations, which include not so much the problems of the development of technologies available on the market but the existing mental limitations that have remained unchanged for centuries in individual economies and societies. These include:

- pervasive selfishness and "business Machiavellianism";
- the desire of businesses and states to monopolise or oligopolise;
- low awareness and responsibility of societies resulting from education systems, e.g., environmental protection; emphasis is placed on increasing specialisation of education, while general education, which is necessary for understanding many phenomena, is overlooked;
- politics and the desire for power.

Egoism and "business Machiavellianism" are nothing more than the implementation by a large number of entrepreneurs of the vision "the end (profit) justifies the means". The effect of following such an approach is that the search for universal solutions and the strategic view of entrepreneurship other than through the lens of profit ceases in most cases (Skobelev & Borovik, 2017, pp. 308–309). This, of course, is aimed at gaining a competitive advantage, which is supposed to take the shape of an oligopoly or monopoly while failing to realistically assess the negative consequences of these actions.

If this is compounded by the low awareness and responsibility of societies, translating environmental issues to the next generation or looking to environmental issues to improve competitiveness and profit, a grim picture emerges of the destructive industry's impact on the environment. The lack of general education does not allow employees and managers to look at processes and the sphere of product design in a broader, systemic way, as they are often very elaborate and multidimensional. Of course, the vision of Society 5.0, or Long Life Learning, assumes that enlightened societies will eventually emerge, but the changes and differences taking shape in the younger generation, unfortunately, predict no illusions that the S 5.0 trend will not dominate for too long.

The presented L&SC 4.0 model considers the latest trends and presents an idea about the future of logistics and supply chain. It also shows the direction for changes in logistics and supply chains. It is a good contribution to open the discussion on logistics and supply chains of the future.

This new concept could not be practically tested because all the shown connections do not exist. However, it should be noted that individual aspects of the model have their own practical version, and in such cases, the behaviour of the system has been observed, and the conclusions of these observations are included in this model.

As a suggestion for further research, the proposed model should be evaluated periodically in response to ever-changing situations in contemporary supply chains. Three main aspects should be considered:

new relationship-based changes between supply chain members, new and emerging technologies enabling more efficient and reliable information flow and overcoming territorial demands of supply chains based on novelties in the first two aspects.

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Gerontechnology ranking using the TOPSIS methods

Katarzyna Halicka
Arkadiusz Gola

ABSTRACT
Population ageing is a major challenge affecting the future of science and technology policy and governance in industrialised societies. In this context, a key element is ensuring adequate protection, safety and care for older people when needed. The solution to enable active and healthy ageing is innovative technologies called gerontechnologies, which support older people. However, there is a knowledge gap regarding the systematic analysis and evaluation of gerontechnologies, which requires research in theoretical and empirical aspects. There is a need to focus on developing and supporting gerontechnologies to help older people reach their full potential in different spheres of life. Research should focus on analysing these technologies, their effectiveness and their impact on the quality of life of older people. This paper evaluates, analyses and builds a ranking of several selected technologies: (1) the wheelchair based on artificial intelligence Wheelie7, (2) the humanoid Rudy Robot, and (3) the wristband/watch VitalBand. The research was conducted in Poland. Based on a literature review, the authors identified relevant technologies to improve the quality of life of older people. These technologies were then assessed by people over 40 against various criteria. This age group was chosen because the issues of gerontechnology concern these people now in the context of their parents using the technology and being potential users of gerontechnology in 20–30 years. The study answered the following research questions: (1) What are the criteria for evaluating technologies that enhance the quality of life for older individuals? (2) How were the selected gerontechnologies evaluated? (3) How should the TOPSIS method be applied to build a ranking of gerontechnologies? (4) Which of the selected gerontechnologies was rated the highest by potential users?

KEY WORDS
technology management, gerontechnology, ranking, Multiple Criteria Group Decision Making, TOPSIS

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Katarzyna Halicka

Bialystok University of Technology, Poland
ORCID 0000-0001-6370-8995

Corresponding author:
e-mail: k.halicka@pb.edu.pl

Arkadiusz Gola

Lublin University of Technology, Poland
ORCID 0000-0002-2935-5003

Introduction

The challenge for many developed countries in Europe and the world is the changing structure of society, in which older people constitute an increasing share (Eurostat, 2023). At the same time, the life model is changing, in which multi-generational family farms are replaced by single- or two-generation families, where an increasing share of time is devoted to the professional work of adults and learning (also in the form of additional activities) of children and adolescents. Consequently, caring for older people,

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which often requires constant attention for health reasons, becomes a significant problem (Scott et al., 2019).

In response to such challenges, retirement homes, also called senior, nursing or older people's homes, are becoming increasingly more important (Siefert & Schelling, 2018). Unfortunately, even though the number of such entities is systematically growing, the problem is to employ sufficient staff with appropriate qualifications to care for older adults. It should be emphasised that proper care for older adults includes aspects related to the implementation of typical life activities (meals, laundry, and taking medications) and social aspects, such as conversation, closeness, understanding, tenderness, etc.

Although comprehensive care for older adults can only be provided by other people, in the era of the development of information technologies and robotics, technological solutions to meet the challenges of caring for older adults, known as gerontechnology, are becoming increasingly important (Huang & Oteng, 2023).

Ageing populations around the world present unique challenges for older adult's care, health, and quality of life. As life expectancy increases, there is a growing need to develop innovative solutions to enable active and healthy ageing and improve quality of life in later years. Gerontechnology is one key area gaining increasing importance in the context of ageing. It is an interdisciplinary field combining technical, health and social sciences to create innovative technological solutions to support older people's daily lives. In today's digital age, technology can play a key role in increasing independence, improving health, and providing comfort for older people. Gerontechnology covers various technologies, from smart home devices and wearable gadgets to telemedicine systems and robotics. However, with many technologies available, the question arises: How should gerontechnologies be ranked and ordered?

This article focuses on the importance of gerontechnology ranking and methods for making such an assessment. Ranking gerontechnologies is an important tool that helps to identify the most effective and useful solutions adapted to the needs of older people. It covers various aspects of technological innovation, including health, social, economic, and technical aspects.

As technology develops at an alarming rate, the gerontechnology ranking becomes even more relevant. It allows for informed selection and investment in solutions that bring the greatest value to older people and ageing societies. However, developing effective gerontechnology ranking methods is challenging, given the variety of technologies available and their complexity.

This article discusses different approaches to ranking gerontechnologies, including methods for assessing effectiveness, indicators for evaluating quality of life and economic aspects of innovation. In addition, it identifies the key factors considered for ranking and discusses the challenges of evaluating technological solutions for older people.

Evaluating and ranking gerontechnology is a process that can help direct innovations so they would meet the real needs of older people and contribute to improving their quality of life. It is worth exploring this area to better understand how technology can support ageing societies.

This article presents the results of empirical research on the use of three technological solutions, i.e., (1) the wheelchair based on artificial intelligence Wheelie7, (2) the humanoid Rudy Robot, and (3) the wristband/watch VitalBand, for the support of care for older adults. The results of surveys conducted on a group of 1152 Polish residents over 40 were analysed.

The research conducted as part of the article aimed to find answers to the following research questions:

- What are the criteria for evaluating technologies that enhance the quality of life for older individuals?
- How were the selected gerontechnologies evaluated?
- How should the TOPSIS method be applied to build a ranking of gerontechnologies?
- Which of the selected gerontechnologies was rated the highest by potential users?

The article is divided into five parts. After the introduction, the first chapter reviews the literature and presents different authors' visions of gerontechnology. The second chapter presents the entire research procedure, techniques used in the research, sample distribution, etc. The next chapter describes research results, aiming to identify the most sought-after gerontechnologies in society and develop a ranking of selected gerontechnologies. The ranking was built using two TOPSIS methods. The article ended with research conclusions. The research techniques used in the study are CAWI (computer-assisted Internet interview) and the TOPSIS method.

1. Literature review

Due to current challenges in the field of care for older adults, gerontechnology is becoming the subject of many scientific studies. For the first time, the issue of gene technology was discussed in greater detail during the 1st International Congress on Gerontechnology, during which work results were presented by, among others, Bouma (1992), Vermijs and Vanbeurden (1992), Henny, Collins and Platts (1992) and Sixsmith and Sixsmith (1992). Since then, research has been conducted in many directions. Some researchers focused on identifying the causes of difficulties in adapting modern technologies supporting the functioning of older people (Chen & Chan, 2014; Gullà et al., 2015; Wu et al., 2015; Yusif et al., 2016; Bevilacqua et al., 2020). Other research efforts emphasise the importance of gerontechnology in the context of modern technologies that can be implemented to support older people and problems with employing staff for this type of work (Cook et al., 2020; Robinson et al., 2020). Many researchers also emphasise the importance of gerontechnology as an important tool to support older adults and care-providing employees and family members (McHugh & Lawlor, 2012; Hopwood et al., 2018).

A significant part of the research focused on aspects related to technologies used to care for older adults. According to published research results, one of the key motivations for accepting gerontechnology was the usefulness of the technology dedicated to this purpose. Numerous studies have demonstrated that older individuals utilise technology in various aspects of their lives, such as cooking, facilitating daily routines, communication, and entertainment. This has been highlighted in the research conducted by Delbreil and Zvobgo (2013), Portet et al. (2013), Menghi et al. (2017), and Huang et al. (2021). Likewise, several scholars have pointed out that the acceptance of gerontechnology significantly impacts the satisfaction of older people's personal needs across different life domains. Examples include Arthanat et al. (2019), Jarvis et al. (2020), and Reitsma et al. (2019). These studies reveal that older adults' technology adoption is driven by their desire for improved health, achievement, independence, and peace of mind.

Furthermore, research has indicated that older adults' attitudes towards technology use are influenced by their willingness to invest in technology, as demonstrated by Peek et al. (2016). Additionally, the frequency of technology use enhances communication with close and significant individuals, as observed by Ollevier et al. (2020). Beyond personal advantages, the value of gerontechnology is closely intertwined with its social benefits. Literature suggests that the perceived utility of gerontechnology can lead to the creation of new job opportunities and tangible improvements in overall quality of life, as Wilson et al. (2021) exemplified. It is also noteworthy that the perceived usefulness of gerontechnology has been acknowledged as a vital factor in enhancing the health and safety of older adults by individuals caring for them, as evident in the studies by Delbreil and Zvobgo (2013) and Cohen et al. (2016). In summary, it can be concluded that the perceived usefulness of gerontechnology can offer numerous personal and social benefits for older individuals and their family members and caregivers.

Graafmans et al. (1998) took a comprehensive look at the role of technology in improving the quality of life of older people. They discussed various gerontechnology aspects, including social, economic and health aspects. Kwon (2017) discussed current research and practice in technology and human ageing. He focused on technologies that support older adults' care and the design and evaluation aspects of such solutions. In contrast, Pak and Collins McLaughlin (2018) examined the impact of technology on the health and quality of life of older people. Various gerontechnology areas are discussed, such as telemedicine and smart homes. Issues related to telemedicine have been discussed by Wu et al. (2023). They present a remote CGA (Comprehensive Geriatric Assessment), which enables early disease detection, monitors chronic disease progression, provides personalised care, and optimises healthcare resources for better health outcomes in older people. In contrast, Maia et al. (2023) introduced an interactive technology to prevent falls in older adults. Forkan et al. (2023) delineated a personalised Internet of Things (IoT)-based Ambient Assisted Living (AAL) system designed to empower older individuals to lead independent and secure lives within the comfort of their homes. This system operates through real-time monitoring and intervention. The HalleyAssist system, leveraging smart home automation features, offers a novel approach for monitoring well-being and promptly identifying any abnormal changes in the behavioural patterns of older individuals. The innovative aspect of this approach lies in utilising machine learning models that autonomously learn an individual's typical behavioural patterns based on data from IoT sensors. These models are then harnessed to detect significant deviations in behavioural patterns when they occur. The paper presents the system's architecture and proof of concept and explores the measures taken to address privacy and security concerns. Additionally, the study includes the outcomes of a home trial conducted with an initial version of the system, during which it was deployed in the residences of four elderly participants for six weeks.

In contrast, the paper (Chaparro et al., 2023) proposes an architectural model for a mixed reality ecosystem to support the daily activities of older people. The paper recommends designing ecosystem elements that can be used in two scenarios to rehabilitate patients' visual-constructive abilities, creating a more appropriate and detailed connection and implementing connectivity, software and peripherals. In contrast, Chan et al. (2008) focused on smart homes as a key aspect of gerontechnology. They presented various technological solutions to support older people in their daily lives. In contrast, Asghar et al. (2017) focused on assistive technologies for the elderly and analysed trends in this field. In their study, Gasteiger et al. (2021) delved into the usability, acceptability, and perceptions of cognitive games delivered via a robot equipped with movable interactive blocks among older adults residing in the community. The findings underscored that cognitive games administered through a robot could supplement existing cognitive stimulation activities. Notably, the robot was deemed user-friendly and instrumental in enhancing cognitive functioning. On the other hand, Ejdys and Gulc (2022) aimed to identify the key determinants of the successful adoption of a specific gerontechnology in Poland. They focused on the Rudy Robot, an AI-powered mobile solution designed to support users in maintaining physical health, cognitive acuity, and social connections. The research confirmed that the Rudy Robot's functionality for the care of older adults positively impacted older individuals' willingness to embrace it for their own needs or those of their family members. The outcomes validated the utility of robots as assistive technology for older adults.

Unfortunately, despite the large number of studies published so far, very few are devoted to selecting the right technology for the needs of older people. This became the goal for the research work presented in this article.

2. Research methods

The entire research process consists of four main stages (Table 1). Based on a thorough literature review, the first stage identifies the technologies assessed in the following stages to build a ranking. Based on previous research by the authors, respondents believed that gerontechnologies addressing issues related to mobility, safety and health were the most important. Therefore, the selected technologies should belong to these groups. In addition, the technologies should be commercially available, easy to use and functional (Ejdys, 2018). Finally, three technologies were selected for further evaluation: the wheelchair based on artificial intelligence: Wheelie7 (GT1), Rudy Robot (GT2), and VitalBand (GT3). The VitalBand watch can measure, display, transmit and communicate information on heart rate, respiratory rate, blood pressure, number of steps, movement, and calories burned. It can be used to measure and manage information on an older person's fitness, vital signs and physical activity. The watch interface is adapted to the needs and capabilities of an older person. Connected to VitalCare, real-time vital signs data is collected via integrated medical devices. By creating a daily and historical awareness of physiological data, patients monitor themselves better and can quickly take self-care action. Patients are involved in their care plans, marking their medications as taken, missed or omitted, helping with adherence and improving the quality of care. With VitalCare Family, relatives can track whether a patient has taken medication,skipped a dose and/or read notes entered

Tab. 1. Research process for the construction of the ranking of selected gerontechnologies using the TOPSIS method

Stage number	Name of stage	Methods used
STAGE 1	Identification of gerontechnologies	Literature review
STAGE 2	Identification of evaluation criteria for selected gerontechnologies	Literature review
STAGE 3	Evaluation of gerontechnologies	CAWI survey
STAGE 4	Construction of the ranking	TOPSIS

by the patient or the doctor. Conversely, Wheelie7, the wheelchair driven by artificial intelligence, stands out as the planet's inaugural innovation, granting elderly individuals the ability to steer the wheelchair using only their facial expressions. The Wheelie7 system swiftly identifies the user's facial expressions and instantly interprets them to navigate the wheelchair's path. The ten gestures discerned by the Wheelie7 wheelchair prototype include smiling, raising eyebrows, and wrinkling the nose. The Rudy Robot accompanies an older person all day long. It helps with mobility and simple tasks and reminds the person to take medication. It is also a good companion for games and activities (Ejdys & Halicka, 2018).

In the second stage, 42 technology assessment criteria were selected based on the literature review. These criteria were sorted into seven groups: (1) Innovation (I1–I4); (2) Technology Demand (D1–D8); (3) Social–Ethical (SE1–SE6); (4) Ecological (E1–E8); (5) Ease of Use (EoU1–EoU4); (6) Functionality (F1–F5); and (7) User Attitude (UA1–UA7).

The third stage uses the criteria identified in stage two to evaluate the three selected technologies (Halicka & Surel, 2021). Respondents evaluated three technologies, i.e., VitalBand, Rudy Robot, and Wheelie7, using the 42 identified criteria. The study engaged individuals above the age of 40. The selection of participants within this age bracket stems from the relevance of gerontechnology matters to this demographic, considering their present involvement with such technology for their parents' care. Additionally, these individuals could become prospective users of gerontechnology in the upcoming 20–30 years. The survey was executed between December 2021 and January 2022, encompassing a representative cross-section of 1152 Polish citizens. A 7-point Likert scale was used, where 1 meant "I definitely disagree" and 7 — "I definitely agree". Along with the questionnaire, respondents were given information about the three technologies, their applicability, pictures, and links to websites.

In stage four, a gerontechnology (GT) ranking was constructed using the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method. This method was chosen arbitrarily. It is one of the most widely used methods and involves selecting the option with the smallest distance from the ideal solution and the largest distance from the least desirable solution (Behzadian et al., 2012). The TOPSIS method was first described by Hwang and Yoon in 1981 (Hwang & Yoon, 1981). The popularity

Yoon in 1981 (Hwang & Yoon, 1981). The popularity of the TOPSIS method is influenced by its simplicity and, more importantly, its adaptability to the input data (Kozlowska, 2022; Halicka & Kacprzak, 2021). The classical TOPSIS method uses two reference points, the first point being the so-called ideal solution and the second — negative ideal solution (Wieckowski & Salabun, 2020). The optimal solution should be closest to the ideal and be as far away from the negative ideal solution as possible (Ozkaya & Erdin, 2020). As the increasing complexity of the decision problems under analysis makes it less feasible for a single decision-maker to consider all relevant aspects of the problems, group decision-making is necessary. Let DM_k $(k = 1,2,\dots,K)$ be a group of decision-makers. Mathematically, the TOPSIS method for group decision-making with aggregation of individual decisions can be described in the following steps:

Step 1: Formulating the decision problem, i.e., defining what will be addressed next (Wartobski et al., 2020).

Step 2: Identifying, based on the formulated decision problem, a set of criteria C_j $(j = 1, 2, \dots, n)$ and the set of options to be selected GT_i $(i = 1, 2, \dots, m)$ (Varatharajulua et al., 2021).

Step 3: Breaking down criteria into stimulants $(C_j \in B)$ and destimulants $(C_j \in C)$.

Step 4: Determining the vector of criteria weights w_j $(j = 1, 2, \dots, n)$ corresponding to the individual criteria (Shekhovtsov & Kolodziejczyk, 2020).

Step 5: Calculating x_{ij}, i.e., evaluating the option GT_i in relation to the criterion C_j.

Step 6: Constructing the decision matrix X^k $(k = 1,2,\dots,K)$, assuming that each decision-maker DM_k has provided his/her decision matrix (individual decision) (Hasnain et al., 2019):

$$X^k = \left[x_{ij}^k\right]_{m\times n} = \begin{matrix} GT_1 \\ GT_2 \\ \vdots \\ GT_m \end{matrix} \begin{bmatrix} x_{11}^k & x_{12}^k & \cdots & x_{1n}^k \\ x_{21}^k & x_{22}^k & \cdots & x_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^k & x_{m2}^k & \cdots & x_{mn}^k \end{bmatrix} \quad (1)$$

Step 7: Normalising the decision matrix X^k $(k = 1,2,\dots,K)$ (Kacprzak, 2019):

$$R^k = \left[r_{ij}^k\right]_{m\times n} = \begin{matrix} DM_k \\ GT_1 \\ GT_2 \\ \vdots \\ GT_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} r_{11}^k & r_{12}^k & \cdots & r_{1n}^k \\ r_{21}^k & r_{22}^k & \cdots & r_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1}^k & r_{m2}^k & \cdots & r_{mn}^k \end{bmatrix} \end{matrix} \quad (2)$$

where:

$$r^k{}_{ij} = \frac{x^k{}_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}. \quad (3)$$

Step 8: Using a vector of weights $w = (w_1, w_2, \ldots, w_n)$ to determine the weighted normalised decision matrix V^k for each criterion DM_k $(k = 1,2, \ldots, K)$:

$$V^k = [v_{ij}^k]_{m\times n} = \begin{array}{c} DM_k \\ GT_1 \\ GT_2 \\ \vdots \\ GT_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} v_{11}^k & v_{12}^k & \cdots & v_{1n}^k \\ v_{21}^k & v_{22}^k & \cdots & v_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1}^k & v_{m2}^k & \cdots & v_{mn}^k \end{bmatrix} \end{array} \quad (4)$$

where:

$$v_{ij}^k = r_{ij}^k \cdot w_j$$

Step 9: Calculating the aggregate weighted normalised decision matrix for group decision-making.

One of the most popular and widely used group decision-making methods is the aggregation of individual standardised matrices V^k $(k = 1,2, \ldots, K)$ into an aggregated collective matrix V according to the formula:

$$V = [v_{ij}]_{m\times n} = \begin{array}{c} \\ GT_1 \\ GT_2 \\ \vdots \\ GT_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \end{array} \quad (5)$$

The most common aggregation methods are:

ART — arithmetic mean (Wang & Chang, 2007):

$$v_{ij} = \frac{1}{K}\sum_{k=1}^{K} v_{ij}^k, \quad (6)$$

GEO — geometric mean (Ye & Li, 2009):

$$v_{ij} = \left(\prod_{k=1}^{K} v_{ij}^k\right)^{\frac{1}{K}}. \quad (7)$$

Step 10: Determining coordinates of the ideal solution (pattern) A^+ and the negative ideal solution A^- (Pawanr et al., 2019).

The ideal solution has the form:

$$A^+ = \{v_1^+, v_2^+, \ldots, v_n^+\}, \quad (8)$$

where:

$$v_j^+ = \{max_i v_{ij}, j \in B \;\; min_i v_{ij}, j \in C\}; \quad (9)$$

a negative ideal:

$$A^- = \{v_1^-, v_2^-, \ldots, v_n^-\}, \quad (10)$$

where

$$v_j^- = \{min_i v_{ij}, j \in B \;\; max_i v_{ij}, j \in C\}. \quad (11)$$

Step 11: Determining the distance of the considered options from the ideal solution d_i^+ (Nowak et al., 2020):

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2} \quad (12)$$

and a negative ideal solution d_i^- (Nowak et al., 2020):

$$d_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}. \quad (13)$$

Step 12: Determining the coefficients RC_i determining the relative proximity of the decision options to the ideal solution (Kacprzak, 2020; Yue, 2014):

$$RC_i = \frac{d_i^-}{d_i^+ + d_i^-}, \quad (14)$$

where $RC_i \in [0; 1]$

Step 13: Building a final ranking of the decision options due to the value of RC_i. The ranking is built from the largest coefficient value to the smallest (Ezhilarasan & Vijayalakshmi, 2020). This means that the most favourable decision options are those with the highest values of the relative proximity coefficient.

The described algorithm allows for the selection of a leader when the input is real numbers. The following subsection will describe the case of the TOPSIS method, which is used to identify the leader when interval numbers are given.

3. Research results

The research aimed to build a ranking of selected gerontechnologies $\{GT_1, GT2_2, \mathrm{GT}_3\}$. These technologies are evaluated by a group of 1152 decision-makers, i.e., $\{DM_1, DM_2, \ldots, DM_{1152}\}$. Each decision-maker rated each technology against 42 criteria, using the following point scale: $\{1,2, \ldots, 7\}$.

The classic TOPSIS method was applied to the pooled matrix after aggregating the individual matrices provided by the DM using the arithmetic mean — TOPSIS_ART and the geometric mean — TOPSIS_GEO.

According to the presented test methodology, a vector of criteria was determined. The criteria weights were determined using the entropy method (Halicka & Kacprzak, 2021; Lotfi & Fallahnejad, 2010). The vector of weights for aggregation using the arithmetic mean is shown in Table 2, and for aggregation using the geometric mean in Table 3.

According to formulas 5, 6 and 7, a weighted normalised decision matrix V_ART and V_GEO was determined (Tables 4 and 5).

Then, formulas 8, 9, 10 and 11 were used to determine the coordinates of the ideal solution (pattern), A^+ and negative ideal (anti-pattern) A^-, for aggregation using the arithmetic mean (Table 6) and the geometric mean (Table 7).

Then, formulas 12, 13 and 14 were used to determine the distances of the variants under consideration from the ideal and negative ideal solutions, d_i^+ and negative ideal solution d_i^- , and the final ranking of the variants (R) of the decision-making variants due to the value of the coefficient RC_i for aggregation using the arithmetic mean and geometric mean method. These values are shown in Table 8.

It should be observed that the ultimate outcomes achieved for TOPSIS_ART and TOPSIS_GEO display slight discrepancies due to distinct methods of aggregation. Nevertheless, despite the variance in aggregation techniques, both TOPSIS_ART and TOPSIS_GEO yield identical rankings for gerontechnologies when considering the formula (the symbol ≺ indicates worse than): $GT_2 \prec GT_3 \prec GT_1$.

In both cases, Wheelie7 was rated the highest. This technology is ranked first. Rudy Robot received the lowest rating.

Tab. 2. Weights of objective criteria determined by the entropy method for aggregation using the arithmetic mean

	I1	I2	I3	I4	D1	D2	D3	D4	D5	D6	D7	D8	SE1	SE2
w_i	0.031	0.051	0.045	0.048	0.043	0.048	0.044	0.020	0.014	0.042	0.040	0.011	0.014	0.017
	SE3	**SE4**	**SE5**	**SE6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EoU1**	**EoU2**
w_i	0.023	0.005	0.003	0.008	0.029	0.012	0.005	0.006	0.001	0.006	0.006	0.006	0.009	0.030
	EoU3	**EoU4**	**F1**	**F2**	**F3**	**F4**	**F5**	**UA1**	**UA2**	**UA3**	**UA4**	**UA5**	**UA6**	**UA7**
w_i	0.005	0.038	0.051	0.049	0.041	0.032	0.003	0.025	0.019	0.028	0.015	0.023	0.024	0.030

Tab. 3. Weights of objective criteria determined by the entropy method for aggregation using the geometric mean

	I1	I2	I3	I4	D1	D2	D3	D4	D5	D6	D7	D8	SE1	SE2
w_i	0.030	0.045	0.044	0.049	0.047	0.046	0.042	0.024	0.017	0.018	0.021	0.013	0.019	0.018
	SE3	**SE4**	**SE5**	**SE6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EoU1**	**EoU2**
w_i	0.026	0.003	0.002	0.007	0.023	0.009	0.003	0.004	0.000	0.005	0.005	0.007	0.007	0.036
	EoU3	**EoU4**	**F1**	**F2**	**F3**	**F4**	**F5**	**UA1**	**UA2**	**UA3**	**UA4**	**UA5**	**UA6**	**UA7**
w_i	0.003	0.051	0.050	0.050	0.043	0.036	0.003	0.031	0.025	0.032	0.018	0.027	0.028	0.033

Tab. 4. Weighted normalised decision matrix V_ART (aggregation using arithmetic mean)

	I1	I2	I3	I4	D1	D2	D3	D4	D5	D6	D7	D8	SE1	SE2
T1	0.019	0.031	0.028	0.030	0.026	0.030	0.027	0.011	0.008	0.023	0.022	0.006	0.009	0.010
T2	0.017	0.028	0.025	0.027	0.023	0.026	0.024	0.011	0.008	0.023	0.023	0.006	0.008	0.009
T3	0.018	0.028	0.026	0.026	0.025	0.027	0.025	0.012	0.008	0.026	0.025	0.006	0.008	0.010
	SE3	**SE4**	**SE5**	**SE6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EoU1**	**EoU2**
T1	0.014	0.003	0.002	0.005	0.018	0.007	0.003	0.003	0.001	0.003	0.003	0.004	0.005	0.018
T2	0.013	0.003	0.002	0.005	0.016	0.007	0.003	0.003	0.001	0.003	0.003	0.004	0.005	0.017
T3	0.013	0.003	0.002	0.005	0.016	0.007	0.003	0.003	0.001	0.003	0.003	0.004	0.005	0.016
	EoU3	**EoU4**	**F1**	**F2**	**F3**	**F4**	**F5**	**UA1**	**UA2**	**UA3**	**UA4**	**UA5**	**UA6**	**UA7**
T1	0.003	0.023	0.032	0.030	0.025	0.019	0.002	0.015	0.011	0.017	0.009	0.014	0.014	0.018
T2	0.003	0.023	0.028	0.027	0.023	0.018	0.002	0.014	0.010	0.015	0.008	0.013	0.013	0.017
T3	0.003	0.021	0.030	0.028	0.023	0.018	0.002	0.014	0.011	0.016	0.009	0.013	0.014	0.018

Tab. 5. Weighted normalised decision matrix V_GEO (aggregation using geometric mean)

	I1	I2	I3	I4	D1	D2	D3	D4	D5	D6	D7	D8	SE1	SE2
T1	0.019	0.029	0.027	0.031	0.029	0.029	0.027	0.014	0.010	0.010	0.011	0.008	0.012	0.011
T2	0.016	0.024	0.023	0.027	0.025	0.025	0.023	0.013	0.009	0.010	0.012	0.007	0.010	0.010
T3	0.017	0.025	0.025	0.027	0.027	0.026	0.024	0.015	0.010	0.011	0.013	0.007	0.011	0.010
	SE3	**SE4**	**SE5**	**SE6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EoU1**	**EoU2**
T1	0.016	0.002	0.001	0.004	0.014	0.006	0.002	0.002	0.000	0.003	0.003	0.004	0.004	0.022
T2	0.014	0.002	0.001	0.004	0.013	0.005	0.002	0.002	0.000	0.003	0.003	0.004	0.004	0.021
T3	0.015	0.002	0.001	0.004	0.013	0.005	0.002	0.002	0.000	0.003	0.003	0.004	0.004	0.019
	EoU3	**EoU4**	**F1**	**F2**	**F3**	**F4**	**F5**	**UA1**	**UA2**	**UA3**	**UA4**	**UA5**	**UA6**	**UA7**
T1	0.002	0.031	0.032	0.032	0.027	0.022	0.001	0.019	0.015	0.020	0.011	0.016	0.017	0.020
T2	0.002	0.030	0.027	0.027	0.023	0.019	0.001	0.017	0.014	0.017	0.010	0.014	0.015	0.018
T3	0.002	0.026	0.029	0.028	0.023	0.020	0.001	0.018	0.014	0.018	0.010	0.015	0.016	0.020

Tab. 6. Coordinates of ideal and negative ideal solution for aggregation using arithmetic mean

	I1	I2	I3	I4	D1	D2	D3	D4	D5	D6	D7	D8	SE1	SE2
A^+	0.019	0.031	0.028	0.030	0.026	0.030	0.027	0.012	0.008	0.026	0.025	0.006	0.009	0.010
A^-	0.017	0.028	0.025	0.026	0.023	0.026	0.024	0.011	0.008	0.023	0.022	0.006	0.008	0.009
	SE3	**SE4**	**SE5**	**SE6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EoU1**	**EoU2**
A^+	0.014	0.003	0.002	0.005	0.018	0.007	0.003	0.003	0.001	0.003	0.003	0.004	0.005	0.018
A^-	0.013	0.003	0.002	0.005	0.016	0.007	0.003	0.003	0.001	0.003	0.003	0.004	0.005	0.016
	EoU3	**EoU4**	**F1**	**F2**	**F3**	**F4**	**F5**	**UA1**	**UA2**	**UA3**	**UA4**	**UA5**	**UA6**	**UA7**
A^+	0.003	0.023	0.032	0.030	0.025	0.019	0.002	0.015	0.011	0.017	0.009	0.014	0.014	0.018
A^-	0.003	0.021	0.028	0.027	0.023	0.018	0.002	0.014	0.010	0.015	0.008	0.013	0.013	0.017

Tab. 7. Coordinates of the ideal and negative ideal solution for aggregation using geometric mean

	I1	I2	I3	I4	D1	D2	D3	D4	D5	D6	D7	D8	SE1	SE2
A^+	0.019	0.029	0.027	0.031	0.029	0.029	0.027	0.015	0.010	0.011	0.013	0.008	0.012	0.011
A^-	0.016	0.024	0.023	0.027	0.025	0.025	0.023	0.013	0.009	0.010	0.011	0.007	0.010	0.010
	SE3	**SE4**	**SE5**	**SE6**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EoU1**	**EoU2**
A^+	0.016	0.002	0.001	0.004	0.014	0.006	0.002	0.002	0.000	0.003	0.003	0.004	0.004	0.022
A^-	0.014	0.002	0.001	0.004	0.013	0.005	0.002	0.002	0.000	0.003	0.003	0.004	0.004	0.019
	EoU3	**EoU4**	**F1**	**F2**	**F3**	**F4**	**F5**	**UA1**	**UA2**	**UA3**	**UA4**	**UA5**	**UA6**	**UA7**
A^+	0.002	0.031	0.032	0.032	0.027	0.022	0.001	0.019	0.015	0.020	0.011	0.016	0.017	0.020
A^-	0.002	0.026	0.027	0.027	0.023	0.019	0.001	0.017	0.014	0.017	0.010	0.014	0.015	0.018

Tab. 8. Gerontechnology rankings using TOPSIS_ART and TOPSIS_GEO

Gerontechnology	TOPSIS_ART				TOPSIS_GEO			
	d_i^+	d_i^-	$\boldsymbol{RC_i}$	$\boldsymbol{R}$	d_i^+	d_i^-	$\boldsymbol{RC_i}$	$\boldsymbol{R}$
GT1 (Wheelie7)	0.004	0.012	0.746	1	0.002	0.016	0.896	1
GT2 (Rudy Robot)	0.011	0.003	0.193	3	0.015	0.004	0.228	3
GT3 (VitalBand)	0.009	0.006	0.397	2	0.012	0.006	0.342	2

Discussion and conclusions

The study featured in this article constitutes original research, with its principal objective centred on acquiring novel insights into discerning the requisites and anticipations of present and future technology users. The overarching goal is to enhance the quality of life for older adults in Poland by better understanding their needs and preferences.

In their daily lives, older people experience difficulties related to their deteriorating health. Gerontechnology addresses older people's problems and improves their quality of life. Based on this article, such technology enhances the well-being of older individuals by easing their reach to various commodities, services, and infrastructure. The multifaceted spectrum of needs and anticipations within the older demographic, coupled with various technologies sporting many different functionalities, necessitates a comprehensive perspective on gerontechnology matters. This entails pinpointing the clusters of technologies that can effectively address distinct categories of user requirements. One of the objectives of this paper is to evaluate and select three gerontechnologies that address such issues. Based on a thorough literature review, the authors have tentatively identified three gerontechnologies helpful for older people: the wheelchair based on artificial intelligence Wheelie7 (GT1), Rudy Robot (GT2), and VitalBand (GT3). These technologies were assessed against 42 criteria: four were related to innovation, four were related to ease of use, five included functionality, six were related to socio-ethical aspects, seven were from the user attitude group, and the technology demand and ecological groups had eight criteria each. Technologies were assessed by people aged 40 and over. This age group was chosen deliberately due to respondents having older parents who can use the technologies and also being potential users of gerontechnology in 20–30 years.

The next research stage was to develop a ranking of gerontechnologies to identify the technologies most highly rated by respondents, i.e., meeting their needs and expectations. The TOPSIS method was used to build the ranking. This method consists of selecting the variant with the smallest distance from the ideal variant and the largest distance from the least desirable variant. The survey involved 1152 respondents. Thus, the three selected technologies were evaluated by 1152 decision-makers. It was necessary to aggregate the individual decisions. The arithmetic means and geometric mean method was used for aggregation. In the end, two rankings, TOPSIS_ART and TOPSIS_GEO, were obtained. However, regardless of the aggregation method, the same ranking of the gerontechnologies was obtained. Wheelie7 was ranked the highest. Other studies (Abdi et al., 2021; Astasio-Picado et al., 2022) also concluded that devices using artificial intelligence will become increasingly more important in the care and support of older people in the near future.

In future studies, the authors intend to consider the opinions of decision-makers on the substance of the criteria when creating the ranking. They also plan to extend the research to other technologies. They also intend to conduct research in other European countries. In addition, they intend to expand the catalogue of criteria and develop the rankings using different methods. They also plan to use other data formats, such as fuzzy numbers, interval numbers, etc., to evaluate technologies. The authors hope that these steps will allow for a more comprehensive and holistic understanding of the assessment of gerontechnologies and their position in the market.

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Evaluation of the technological structure of the work programme of construction companies

Romualdas Ginevičius

ABSTRACT
The commercial performance of a construction company (CC) largely depends on the planned work programme. The annual CC work programme is a set of objects of a specific purpose and structure (a building system). The programme has the following characteristics: first, the number of objects; second, the construction technologies provided for in the projects (fully prefabricated, monolithic, brick, etc.); third, the variation of work scopes among objects; and fourth, the construction technology. These CC work programme features are interrelated, i.e., aligned with each other, forming the technological structure (TS) of the CC work programme. Once these attributes were formalised, four partial indicators were obtained: the first assesses the variation in construction objects' sizes; the second — their number; the third — the number of applied technologies; and the fourth — the technologies. The importance of these indicators was assessed to combine them into an indicator of the technological structure of the annual CC work programme. Its quantitative assessment has scientific and practical importance, providing an opportunity to analyse its impact on the results of commercial activities, to improve the organisational management structure of the company, etc.

KEY WORDS
construction technology, evaluation of the technological structure of the work programme of the construction company

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Romualdas Ginevičius

Mykolas Romeris University, Lithuania
ORCID 0000-0003-2067-4398

Corresponding author:
e-mail: romualdas.ginevicius@mruni.eu

Introduction

Under market economy conditions, the formation of the annual work programme of a construction company (CC) is fundamentally different as it consists of projects won in competitions. CCs can only apply for projects within the scope of their construction license. The competent authority issues licences after the construction company submits documents proving its ability to build specific purpose objects, i.e., information about the available material and technical base, qualifications of employees, etc. More

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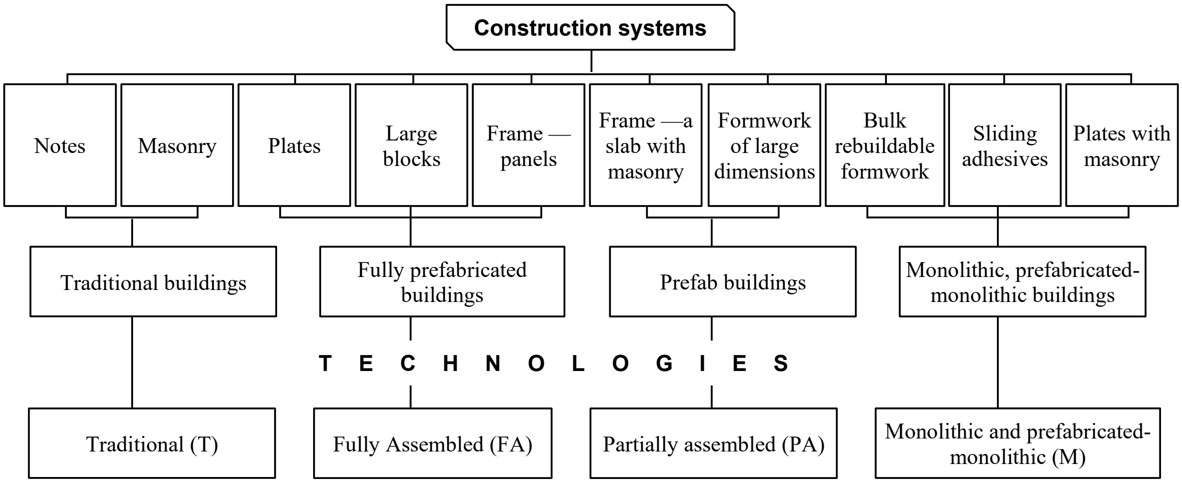

Fig. 1. Basic construction systems and technologies of public and industrial buildings
Source: elaborated by the author based on (Ginevičius, 1995).

diverse construction licenses allow for an easier formation of an annual work programme. On the other hand, a greater variety of objects has an ambiguous effect on the results of commercial activities. This is because different technologies are used to construct different purpose objects, which requires different mechanisms, employees with different qualifications and specialisations, different ways of organising work, etc.

Differences in construction technologies are evident from the definition: it is a set of processes for transforming materials and structures into construction products (Ginevičius, 1995). The definition suggests essential technology features. They differ in the structure of production processes, the performance consistency, and the performance methods.

The composition and consistency of the main construction processes are determined by the sequence of work necessary for the construction of objects, starting with construction preparation and earthworks, moving to construction installation, roof and finishing work.

The third characteristic of technology, the ways of performing production processes, can be different even for the same set of processes and the execution sequence so that it can be the most acceptable criterion for different technologies. The question arises as to what construction work methods depend on, given that a method is a deliberately applied order of actions to achieve a goal. In the context of the execution of construction works, they exclusively depend on the construction system (CS) of the building or structure, reflecting their basic structural solutions. In turn, the methods and means of performing the work depend on the project's construction solutions, i.e., the construction technologies that will be applied (Fig. 1).

Thus, the annual implementation of the CC work programme should be examined through the totality of the applied technologies. The analysis shows that regardless of their nature, this programme is characterised by the same features: first, it consists of a certain number of various purpose objects; second, certain technologies are used for their construction; third, the objects are of different sizes according to their contract price; and fourth, the applied technologies are different. All these signs are interrelated, and a growing number of objects included in the work programme increases the variety of their structural solutions, on which the number of applied technologies and their technological level depend.

Based on the theory of systems, the system's structure is a set of relatively constant connections among its elements; therefore, the features of the CC work programme constitute a system, and its structure can be called a technological structure.

Today, the quantification of the technological structure of the CC work programme is particularly important as the results of commercial activity largely depend on it. Such a possibility requires transforming the reflecting signs into indicators. In this case, it will be possible to apply multi-criteria methods to evaluate the CC's technological structure.

The purpose of the article is to propose and approve the methodology for the quantitative assessment of the technological structure of the annual CC work programme.

1. Literature review

In the market economy, the conditions for carrying out construction work have changed fundamentally. Not only their management and organisation have changed, but also the technologies for performing work and processes. The role of the institution that implements construction projects, the construction company (CC), has changed as well. Its work programme (WP) is formed completely differently. The content of the CC's role analysis in WP implementation follows from versatile functions it has to perform in this process, i.e., finance, personnel, purchases/sales, supply of construction facilities with transport, work contracts, quality and other management. Additionally, a CC also deals with other issues: accounting, subcontracting, estimates, provision of work tools, employee remuneration, material incentives, legislation, etc. (Barvidas, 2010; Belout, Gauvreau, 2004; Anderson, 1992). The costs of implementing all these functions largely depend on the kind of objects within the work programme, i.e., its technological structure (Belout, Gauvreau, 2004). The economic results of the CC's activities directly depend on these costs (Barvidas, 2010) (Fig. 2).

Fig. 2 shows that it is appropriate to examine literature sources analysing the conditions of WP implementation. Most attention is possibly paid to the management of construction projects based on BIM technology (Pezeshki & Ivari, 2018; Xie et al., 2022; Al-Ashmori et al., 2020; Koo et al., 2021; Sun & Kim, 2022) and examination of related information systems (Koo et al., 2019; Love & Irani, 2004). Supply is an important aspect of the analysis on which construction success largely depends (Cataldo et al., 2022; Suhi et al., 2019; Tiwari et al., 2014). The application of sustainability principles in construction is also analysed (Thies et al., 2019; Kamali & Hewage, 2017). A separate research direction is the evaluation of building technology (Lawson et al., 2012; Skibniewski & Chao, 1992; Chao & Skibniewski, 1998; Kim et al., 2011; Nanyam et al., 2015). Also considered are such construction aspects as noise and risk reduction (Love et al., 2020; Abad et al., 2019), waste disposal (Zhang et al., 2021; Naji et al., 2022) and energy issues of buildings (Ajayi et al., 2019), construction solutions for buildings (Lawson et al., 2012), working conditions (Trishch et al., 2021), quality improvement (Love et al., 2020), etc. Various mathematical methods are used for the analysis, mostly for evaluating technological solutions for house construction. Here, multi-criteria methods prevail (Skibniewski & Chao, 1992; Nanyam et al., 2015; Zavadskas et al., 2012; Zavadskas et al., 2013; Turskis et al., 2016). These methods are also applied in the assessment of working conditions (Trishch et al., 2021; Cherniak et al., 2020) and the quality of building materials and structures (Shahbazi et al., 2017). The Delphi method is widely used to assess construction project management (Kamali & Hewage, 2017; Kermanshachi et al., 2020), Fuzzy logic is used for risk assessment (Abad et al., 2019; Chao & Skibniewski, 1998; Liao & Plebankiewicz, 2021), and verbal analysis (Shevchenko et al., 2019) is also used.

The literature review shows that all the studies examine either the management of individual construction projects or the management conditions of the CC's construction functions, i.e., no studies analyse the management of a CC work programme in the context of its technological aspects as a whole. Meanwhile, the impact of its technological structure manifests primarily through changes in the organisational management structure, i.e., the role of services used

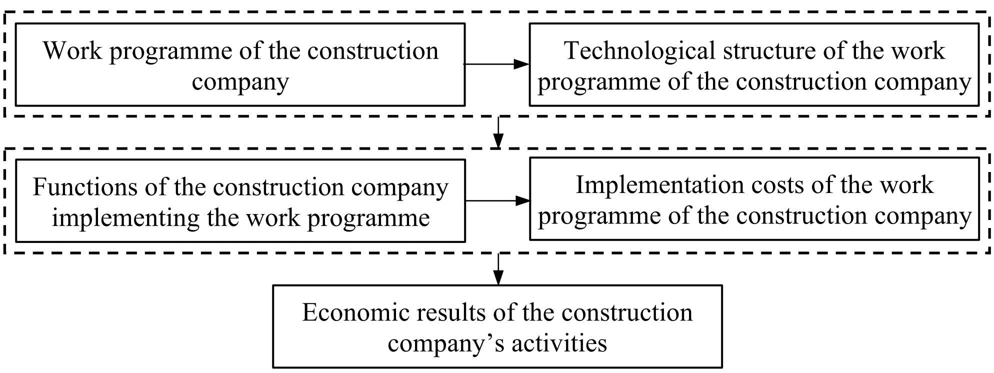

Fig. 2. Effect of the technological structure of the construction company's work programme on the economic results of operations

for construction objects with prevailing technology increases. All this presupposes the need, relevant in both scientific and practical sense, to quantitatively evaluate the technological structure of the CC work programme to determine its impact on the economic results of the activity.

2. Research methodology

The technological structure (TS) indicator of the annual CC work programme has to meet the following requirements:

- The annual CC work programme consists of different purpose objects (residential, public, industrial buildings, etc.) and, therefore, of different constructions. To evaluate it as a whole, the TS indicator must include both quantitative and qualitative aspects of the work programme.
- It is necessary to evaluate the quantitative side of the annual CC work programme because of the different technologies used for construction projects and the variety of objects to be constructed.
- It is necessary to assess the qualitative side of the annual CC work programme because of possibly different sizes of construction objects and different construction technologies used.

After evaluating the requirements for the TS indicator, its calculation scheme looks as provided in Fig. 3.

The changes in the value of the indicator for the technological structure of the annual CC work programme must correspond to Fig. 3. The effects of the specified TS elements.

The number of objects included in the annual CC work programme usually means the diversity and level of the applied technologies, and therefore, higher management and work organisation costs. Therefore, the growing number of work programme objects should decrease the value of the TS indicator.

The same applies to the number of technologies: more technologies applied simultaneously in various objects means a more complicated process for managing and organising the overall construction process. Therefore, as the number of technologies grows, the value of the TS indicator should decrease.

The commercial performance of the construction company also depends on the size of the objects in the work programme. Growing differences make the overall process of construction management and organisation and execution of works less efficient; therefore, the decrease in the uniformity of the work programme must also reduce the value of the TS indicator.

The more diverse technologies are used in the construction of objects, the greater are their technology differences. Meanwhile, the cost of the work and the duration and price of the construction largely depend on it. Therefore, the value of the TS indicator must increase as the technological level of the applied technologies grows. Fig. 4 provides the summarised effect made by the elements of the technological structure indicator on the results of the CC's commercial activity.

Based on Fig. 4, it is possible to proceed with compiling the indicator of the technological structure of the annual CC work programme.

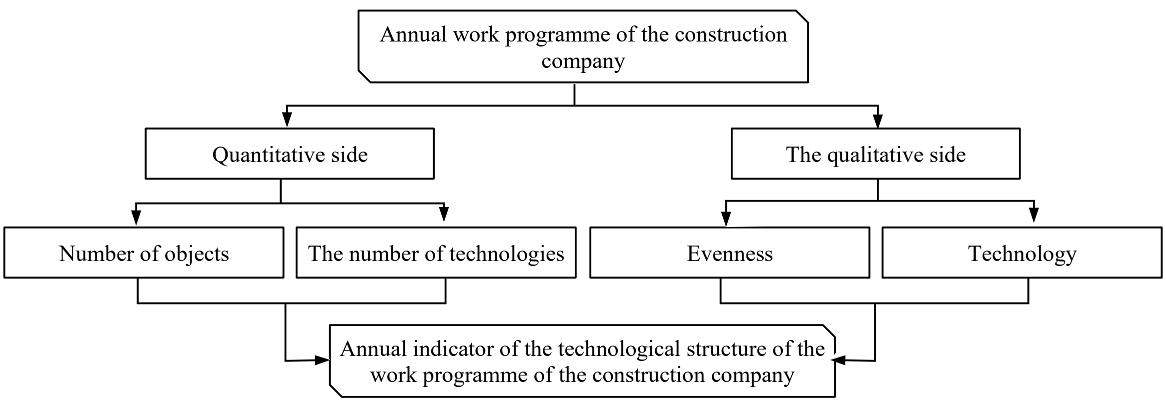

Fig. 3. Calculation scheme of the technological structure of the annual work programme of the construction company

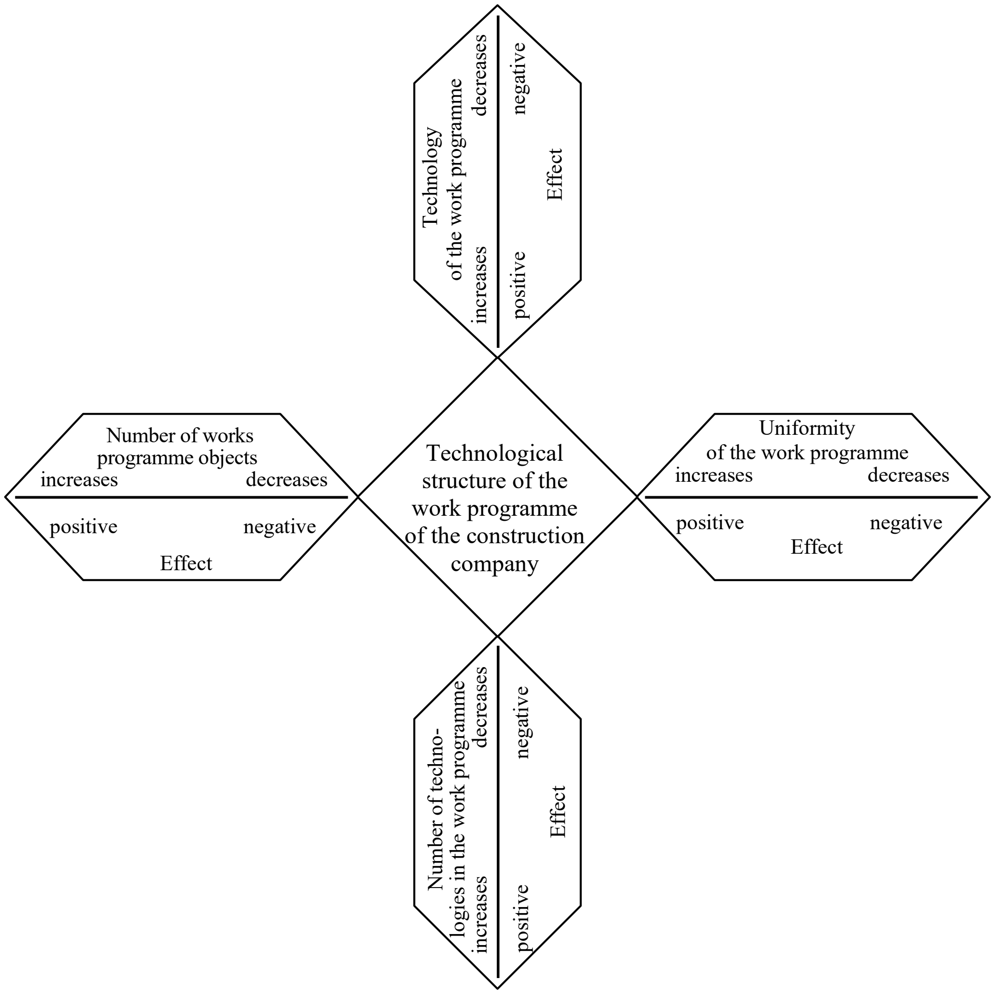

Fig. 4. Effect of the elements of the work programme of the construction company on the technological structure

The variation of the scope of work among the sizes of construction objects included in the annual CC work programme can be determined as follows:

$$K_{TV} = \frac{n-1}{\sum_{i=1}^{n} \frac{Q_{\max}}{Q_i}}, \quad (1)$$

here, K_V is the annual work programme uniformity indicator; $Q_{\max}$ — the size of the largest construction object according to the contractual price in the percentage of the total work scope; Q_i — the size of the i-th object in the percentage of the total work scope; n — the number of objects of the construction work programme ($i = \overline{1, n}$).

Based on formula (1), the maximum value equal to 1.0 K_V is reached when there is no variation, i.e., when $Q_i = Q_{i+1}$. As the variation increases, K_V value approaches 0.

The indicator reflecting the number of objects included in the CC work programme must vary within the same limits as K_T. It can be set as follows:

$$K_{TN} = \frac{1}{n}, \quad (2)$$

here, K_{TN} is the indicator of the number of objects in the annual work programme.

Based on formula (2), the indicator K_N takes on the highest value when the production programme consists of only one object.

The indicator of the annual CC work programme reflecting the number of applied technologies can be determined as follows:

$$K_{TT} = \frac{1}{T}, \quad (3)$$

here, K_{TT} is the indicator of the number of technologies applied in the annual work programme; T — the number of technologies at the level of the CC.

Based on formula (3), the indicator K_{TT} takes on the greatest value when the same technology is used for the construction of all objects of the annual work programme.

First, to determine the technological indicator of the objects of the annual CC work programme, it is necessary to evaluate the technology and predict its rank in construction projects. Based on these ranks, the level of technologies applied for the construction of objects within the annual CC work programme can be determined as follows:

$$K_T = \frac{\sum_{n-1}^{n} S_j \tilde{r}_i}{\sum_{i=1}^{n} \tilde{r}_{\max}}, \qquad (4)$$

K_T — technological efficiency indicator of the technologies applied for the construction of objects within the annual CC work programme; S_j– S_j — the volume of the j-th CS in unit parts; $r_{\max}$ — the highest possible CS technologically transformed rank; r_i — the same, j-th CS.

Technology ranks are transformed to be comparable to S:

$$\tilde{r} = \frac{r}{10}. \qquad (5)$$

Indicators of the technological structure of the annual CC work programme have different importance. For example, CS technology depends on the purpose of the objects included in the work programme and, thus, on their constructive solutions regarding the number of technologies to be applied in the implementation of the annual work programme, etc. Only experts can determine this importance.

After determining the values and importance of the indicators K_{TV}, K_{TN}, K_{TT} and K_r, they can be combined into one summarising quantity reflecting the technological structure of the annual CC work programme (Fig. 4). This can be done based on multi-criteria methods since the TS indicator is represented by four partial indicators. Today, they are widely used to determine the state of the most diverse technical-technological and socio-economic systems at a desired moment in time (Grybaitė, 2023; Išoraitė et al., 2022; Vysochan et al., 2022; Yücel & Görener, 2016; Choi & Choi, 2022). Some of them are simpler; others are more complicated in their application. The idea of these methods is reflected by the most popular and widely used SAW method:

$$K_{SAW} = \sum_{i=1}^{n} \omega_i \tilde{q}_i, \qquad (6)$$

here, K_{SAW} — the significance of the multi-criteria assessment of the state of the considered phenomenon by the SAW method; ω_i — the importance of the i-th indicator; $\tilde{q}_i$ — the normalised value of the i-th indicator.

Multi-criteria evaluation methods, as provided by formula (5), can be applied only when the indicators are expressed in two quantities, i.e., importance and meaning. To combine these transformed values into one summarising quantity, they need to be made comparable, i.e., they must be dimensionless and vary in the same range and in the same direction. When using the multi-criteria SAW method, the normalisation of indicator values is performed as follows (Hwang & Yoon, 1981; Podvezko, 2008):

$$\tilde{q}_{ij} = \frac{q_{ij}}{\sum_{j=1}^{n} q_{ij}}, \qquad (7)$$

here, $\tilde{q}_{ij}$ — the normalised value of the i-th indicator; q_{ij} — the initial value of the i-th indicator; n — the number of indicators ($i = \overline{1, n}$); m — the number of variants ($j = \overline{1, m}$).

The equalisation of the direction of change of indicators is carried out as follows:

a) the values of the indicators minimise:

$$q_{ij} = \frac{\min_j q_{ij}}{q_{ij}}, \qquad (8)$$

b) values of indicators maximising:

$$q_{ij} = \frac{q_{ij}}{\max_j q_{ij}}, \qquad (9)$$

here, $\min_j q_{ij}$ — the smallest value of the i-th indicator among all alternatives; $\max_j q_{ij}$ — the same, the largest.

All indicators of the technological structure of the annual CC work programme are dimensionless and vary in the same range, i.e., from 0 to 1, and also vary in the same direction, i.e., the situation improves as their values increase. Therefore, all of them can be combined without additional calculations into one summarising value, an indicator of the technological structure of the annual work programme of a State Enterprise.

3. Empirical study

The proposed methodology for the quantitative assessment of the technological structure is illustrated using specific examples. The annual work programme of the first construction company consists of ten objects, and the second has seven (Table 1).

Based on the data presented in Table 1, it is difficult to decide which construction company's technological structure of the annual work programme has greater significance since it is better for some TS indicators in one company and for others in another.

An expert survey was organised to determine the technology indicator. Employees selected as experts were responsible for the construction of objects (work managers), technologists, heads of CC departments, etc. A total of 12 experts were chosen. Based on the results of the survey, a summary table of expert evaluation was compiled (Table 2).

When evaluating the number of technologies, the concordance of expert opinions was determined based on Kendall's concordance coefficient W (Kendall, 1975). Its value was found to be equal to 0.72. Hence, the experts' opinions were consistent. The following results were obtained (Table 3).

After calculating the indicators of the technological structure of the work programme based on formulas (1)–(4), the following results were obtained (Table 4).

To determine a general indicator of the technological structure of the CC work programme, a survey of experts was conducted again. The survey involved the same experts who evaluated the technological properties of the objects. The value of Kendall's concordance coefficient W significantly exceeded the required minimum (W = 0.83). According to their opinion, the importance of technological structure indicators was determined: the number of technologies — 0.4, the level of technologies — 0.3, the uniformity of the work programme — 0.2, and the number of construction objects — 0.1.

Tab. 1. Annual work programme of the consideration construction companies (percentage)

Objects of the annual work programme of construction companies		1	2	3	4	5	6	7	8	9	10
The comparative weight of the contract prices of construction objects in the total work scope	first company	10	12	10	12	10	8	12	10	8	8
	second company	5	35	25	10	6	10	9	–	–	–
Object construction technology	first company	M	M	M	PA	FA	PA	FA	M	M	M
	second company	FA	PA	PA	T	M	FA	M	–	–	–

Source: data provided by companies X and Y.

Tab. 2. Expert assessment of the technology of objects in the CC work programme

Technology	Traditional	Fully assembled	Partially assembled	Monolithic and prefabricated-monolithic
Assessment of technology	3	1	2	4

Tab. 3. Technological ranks of construction technologies

Name of the technology	Traditional	Fully assembled	Partially assembled	Monolithic and prefabricated-monolithic
Place of the technology	4	1	2	3
Technology rank	1	4	3	2

Tab. 4. Calculation results of the indicator values of the technological structure of the annual CC work programmes

Construction company	Technological structure indicators			
First	0.672	0.100	0.333	0.652
Second	0.239	0.143	0.250	0.280

Based on formula (6), the value of the technological structure indicator of the first annual CC work programme was 0.47 and 0.24 for the second. These results do not contradict the logic of the proposed methodology. Experts gave the greatest importance to the technological structure of the number of technologies in the annual CC work programme. It is equal to three for the first company and four for the second. Based on formula (2), the first company is in a better position. In second place of importance is the technological nature of the applied technologies. In the first company, the comparative weight of such technologies is higher than in the second. The work programme of the first company also does not include the least advanced technologies. In addition, the value of the technological indicator of the first company is more than 2.3 times higher than that of the second.

The obtained results suggest new scientific research opportunities, as it will be possible to analyse the influence of the technological structure of the CC work programme on various performance results, including economic.

Conclusions

Under the conditions of the market economy, the formation of the annual work programme plays an important role in the activities of construction companies. The analysis shows that regardless of their nature, they all have the same characteristics: first, they consist of a certain number of various purpose objects; second, specific technologies are used for their construction; third, the objects differ in sizes; fourth, the applied technologies differ in their nature. All these features are interrelated and complement each other, so their entirety can be viewed as a system. In the theory of systems, their structure plays a special role, which can be viewed as a generalised characteristic of the system (Ginevičius, 2009). The features of the construction company's work programme, such as elements of the structure, follow from its comprising structural solutions of the buildings or structures. In turn, this depends on the construction technology, so the totality of these features can be evaluated as the technological structure of the CC work programme. The results of the construction company's commercial activity largely depend on it, so its quantitative assessment acquires both scientific and practical significance. For that purpose, the features of the work programme reflecting the technological structure need to be formalised, i.e., transformed into indicators. On the other hand, just knowing the values of the indicators does not yet convey the overall picture of the technological structure. To obtain it, the values of the indicators need to be integrated into a unified index of the technological structure. The importance of the indicators is not the same, so it should be determined based on expert judgments. Having the values and importance of the indicators, it is possible to calculate the technological structure index using multi-criteria methods.

Calculations of the technological structure index for two construction companies with significantly different work programmes confirmed the suitability of the proposed methodology.

Further research may be limited by the possibility of obtaining information about the structure of the annual work programme of construction companies. The strength of the obtained results can be attributed to the novelty of the study, allowing for the quantitative assessment of the technological structure of the annual CC work programme. This enables a more efficient, prompt and accurate management. The conducted research could be extended by highlighting and focusing more on evaluating the impact made by the technological structure on the organisational management structure of a construction company.

Quantitative assessment of the technological structure of the construction company's work programme opens up wide opportunities for relevant research: it will be possible to determine to what extent it affects the commercial activity results of the construction company, optimise the work programme to achieve greater economic efficiency of its implementation, etc.

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Circular manufacturing and Industry 5.0. assessing material flows in the manufacturing process in relation to e-waste streams

Agata Mesjasz-Lech
Ágnes Kemendi
Pál Michelberger

ABSTRACT

The article aims (1) to evaluate material flows in the manufacturing process reflecting the level of circular manufacturing of European Union countries and (2) to estimate the relationship between the level of circular manufacturing and the volume of e-waste put on the market, illustrating the implementation effect of Industry 5.0 technologies. A systematic country classification was created according to development conditions for environmentally sustainable enterprises and trends in e-waste volumes. Multidimensional data analysis and the linear ordering method were used to achieve the research objectives. The dynamics of changes in the identified variables were analysed using dynamics indexes and the average annual rate of change. Relationships were estimated using Pearson's linear correlation coefficient. The main research result is the estimated synthetic development measure illustrating the level of circular manufacturing in the context of material flows. Significant differences were observed between the synthetic development measure values representing the level of circular manufacturing in European Union countries. This means countries' circular manufacturing levels are significantly higher than others. Moreover, the values of correlation coefficients were estimated between the level of circular manufacturing and the volume of e-waste put on the market and between the average annual rate of change of the synthetic development measure and the average annual rate of change of the e-waste volume. The coefficient values do not confirm a statistically significant relationship between the indicated variables. Most countries have average conditions for developing environmentally sustainable businesses, but at the same time, they show negative trends in the volume of e-waste generated.

KEY WORDS

circular economy, environmentally sustainable enterprises, Industry 4.0, Industry 5.0, circular manufacturing, sustainability

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Agata Mesjasz-Lech

Częstochowa University of Technology, Poland
ORCID 0000-0001-9577-2772
Corresponding author:
e-mail: a.mesjasz-lech@pcz.pl

Ágnes Kemendi

Óbuda University, Hungary
ORCID 0000-0002-6452-8563

Pál Michelberger

Óbuda University, Hungary
ORCID 0000-0001-5752-0224

Introduction

Sustainability of the production system and elimination of waste are at the centre of circular manufacturing. Circular manufacturing is a new production approach that helps to create environmentally sustainable enterprises (Le et al., 2023; Gupta et al., 2021). In today's world, circular manufacturing can be regarded as an important aspect of corporate social responsibility. Moreover, this aspect elevates corporate social responsibility to a truly meaningful level beyond a marketing concept.

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Environmental management has been traditionally part of responsible corporate behaviour. The circular manufacturing approach triggers significant change in manufacturing by minimising waste through reducing, reusing/refurbishing, recycling, and recovering (Acerbi et al., 2021a; Acerbi et al., 2021b). This approach helps to reduce the overall environmental impact and revolutionarily transform the production system (Kumar et al., 2019).

Customer expectations are becoming more individualised and complex, driving change in company operations aiming to ensure better availability of products and resulting in increased consumption of company resources, mainly raw materials and energy (Ogiemwonyi et al., 2023). Circular manufacturing is complex and multifaceted; thus, it is difficult to grasp its systemic and dynamic nature (Roci et al., 2022). In a company, the implementation of the R-strategy (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) is seen as its dynamic capability (Mora-Contreras et al., 2023). Digital technologies facilitate the implementation of circular manufacturing systems. Previous research in the context of the impact of Industry 5.0 on the creation of circular economic cycles focused on issues related to the following three areas:

- supporting the circular economy by using Big Data to implement industrial symbioses in cities (Song et al., 2017; Song et al., 2015),
- avoiding wastage of products and materials by optimising flows in supply chains and production systems using Big Data Analytics (Cicculllo et al., 2022; Li et al., 2022) and the Internet of Things (Martikkala et al., 2023; Ramya et al., 2023; Seker, 2022),
- minimising wastage of resources and increasing the level of processing using new technologies such as the Internet of Things, artificial intelligence and machine learning (Said et al., 2023; Andeobu et al., 2022).

The research focus on prioritising the green economy and efficient use of scarce resources is consistent with Huang et al.'s (2022) approach to Industry 5.0. However, Masoomi et al. (2023) pointed out that an important research gap is the lack of a comprehensive framework addressing sustainability challenges, particularly resource efficiency, circular manufacturing, and social and environmental impacts in the context of Industry 5.0. Concerning circular manufacturing, Industry 5.0 technologies support companies in creating circular, smart products (Ghobakhloo et al., 2022), enabling smart and sustainable manufacturing (Sami et al., 2023), enabling circular life cycle (Fraga-Lamas et al., 2021), and sustainable resource management (Paschek et al., 2022). The development and application of advanced information technologies of Industry 5.0 is expected to improve business operations' efficiency and productivity while reducing waste and resource consumption (Psarommatis et al., 2023).

Liu et al. (2023) showed that Industry 4.0 technologies enable the implementation of circular manufacturing, but further rigorous verification of empirical results is needed. The publication explores the environmental context of Industry 5.0/4.0, the goals of circular manufacturing, and the Industry 5.0/4.0 technologies supporting enterprises towards circular activities. The purposes of the article are to evaluate material flows in the manufacturing process reflecting the level of circular manufacturing of European Union countries and to estimate the relationship between the level of circular manufacturing and the volume of e-waste put on the market, which illustrate the effect of the implementation of Industry 5.0 technologies. The adopted goals are based on the assumption that, unlike Industry 4.0, Industry 5.0 technologies are more focused on human needs in the context of sustainable development. Thus, they should support activities with the least possible negative environmental impact. One effect of their implementation should, therefore, be the reduced amount of waste generated through sustainable material flows in terms of the created environmental burden. The publication presents an analysis of the effects of circular manufacturing in the context of the e-waste streams in the European Union countries.

1. Literature review

1.1. Circular manufacturing goals

Today's economy forces manufacturers to change their management model due to three trends: vertical integration, digitisation and cost leadership (Krings et al., 2016). Additionally, extended producer responsibility imposes liability for products on companies in the post-consumer phase (Dan et al., 2023). The drive to be competitive forces manufacturing companies to increase the availability of high-value-added products. As a result, they are implementing new business models allowing them to offer high-quality products to meet demand and, at the same time, promote a new perspective on the role of resources in the economy, thus enabling them to achieve the goals of the circular economy (Wu & Pi, 2023).

The goal of the circular economy is to reduce waste and maximise resource use by extending the life cycle of products. Three characteristics of the circular economy can be distinguished (Ren et al., 2023):

- elimination of waste and pollution in the context of sustainability and renewal rather than in the context of efficiency and waste in terms of products and processes,
- restoration of the value of products and materials (instead of discarding them) through repair, reuse and recycling,
- restoration and regeneration of natural systems to ensure they are available for future generations.

The goals of circular manufacturing, such as extending product life cycles, reducing waste and thereby improving sustainability, can also be achieved through infrastructure for sharing information among ecosystem players (Barata et al., 2022). Actions taken on governmental levels of individual European Union member states or regions to implement the circular economy influence the level of goal achievement connected with, among other things, resource scarcity, climate change, the creation of global value chains and the implementation of UN sustainable development policies (Kulczycka, 2018). Therefore, the activities implemented at the level of the national economy set the course of action for companies with respect to circular production. Active sectoral cooperation with economic players is essential for designing effective strategies and policies that will motivate and eliminate barriers to introducing circular economy programmes in enterprises and support the implementation of new technologies and innovative processes in this regard (Skare et al., 2023).

When measuring circular manufacturing, it is important to consider material flows used in the economy and discharged into the environment or reintroduced into economic processing. Circular manufacturing, which is a characteristic of environmentally sustainable enterprises, is reflected in the country's circular economy. Therefore, circular economy assumptions adopted at the state level set the course for enterprises in this area, creating the right conditions for their operation and decision-making in the context of shaping material flows in closed production loops. For this reason, the following research question was formulated:

Q1: How should circular manufacturing be measured considering material flows used in the economy and discharged into the environment or reintroduced into economic processing?

1.2. Environmental context of Industry 5.0

The Industry 4.0 paradigm is essentially technological and harmonious with the business models' optimisation and economic thinking. However, it is not suitable for environmental and social aspects according to an independent expert report of the European Commission (2021b). The Industry 5.0 paradigm places the Industry 4.0 paradigm in a broader context, widening the strategic focus and going beyond value extraction to shareholders. The Industry 5.0 paradigm recognises the power of industry to achieve societal goals beyond jobs and growth to become a resilient provider of prosperity by making production respect the boundaries of our planet and placing the well-being of the industry worker at the centre of the production process. References to the environment in the context of sustainable development can already be found in the concept of Industry 4.0. Ejsmont et al. (2020) identified seven main areas for supporting sustainability with Industry 4.0 technologies, specifically: management of sustainable product life cycle, achievement of sustainability, implementation of smart manufacturing, achievement of circular economy, achievement of compliance with triple bottom line, achievement of sustainable supply chain, development of new business models and organisational structures. In contrast, Tavares-Lehmann and Varum (2021) indicated that "circular economy" mentioned in the keywords of articles linking Industry 4.0 issues to sustainability ranks only fourth (behind "Industry 4.0", "Sustainability", and "Sustainable development" and ahead of "Manufacturing", "Internet of Things" and "Supply Chain Management"). Industry 5.0 complements the existing Industry 4.0 approach by specifically putting research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry according to the definition of the European Commission (2021a). This concept is accompanied by the evolution of circular economy thinking. The circular economy is meant to overcome the difficulties of the current model focused on continuous growth and efficient resource utilisation (Adlin et al., 2023). Over recent years, sustainability has become an important aspect of corporate management philosophy and has become dominant in business strategy, processes and products (Morea et al., 2021; Formentini & Taticchi, 2016; Varriale et al., 2023). The European Commission adopted the new circular economy action plan in 2020 for a cleaner and more competitive Europe (European Commission, 2020).

The adoption of Industry 5.0 impacts people, the planet and profit that can be measured by the triple bottom line concept, which considers economic impact (e.g., efficiency improvement, increase in productivity, cost reduction, etc.), social impact (e.g., the potential to create new leadership jobs and allow the workforce to develop new skills, improve worker safety and well-being by automating dangerous or repetitive tasks) and environmental impact (e.g., reducing waste, improving energy efficiency, promoting sustainable manufacturing practices. For example, 3D printing can reduce waste by producing parts on demand) (Up-Skill Project, 2023). Each of the three Industry 5.0 pillars is generally present in Industry 4.0. However, Industry 5.0 allows for a broader consideration of social and environmental priorities by shifting from a primarily technology-focused to a more systemic approach.

The paradox of Industry 5.0 lies in its definition that this paradigm puts the human at the centre to realise its revolutionary approach to the Fifth Industrial Revolution. With reference to automation projects, proper and thoughtful risk management is found critical for project success. Risk management should cover the relevant change management activities including the management of the human-factor related risks. The Industry 4.0 paradigm focused on the technological drive rather than human aspects (Jafari et al., 2022). This makes the Industry 4.0 concept suitable for cases where full automation is possible. The Industry 5.0 concept goes further as it is capable of managing unique cases effectively and this is where human skills become valued. Human interaction plays an important role when it comes to customisation and this is well covered by the Industry 5.0 paradigm. The manufacturing industry serves to meet customer requirements where innovation and resilient reactions are mostly in demand.

Studies show that companies using digital tools increase the efficiency of reusing products, create relationships with customers, enable data collection and analysis, and provide an assessment of post-use phase product handling options that can potentially extend product life and improve recycling efficiency (Wu & Pi, 2023). The use of Industry 5.0 solutions to create circular manufacturing is all the more desirable as this manufacturing model is considered one of the engineering solutions for fostering sustainability (Ghimouz et al., 2023). For example, machine learning, which in the context of circular manufacturing can be used in controlling production, maintenance, recycling and remanufacturing processes, allows an increase in the profitability of production systems and their resistance to emerging failures (Paraschos et al., 2022). Another solution using new information technologies is additive manufacturing (AM), which supports waste reduction and extends the life of materials (Valera et al., 2023). Research conducted by Tavares et al. (2023) demonstrates 15 potential benefits of AM leading to the circular economy associated with each of the six ReSOLVE principles:

- Regenerate: promoting biodegradable materials use and energy from renewable sources, promoting the recovery, retention and restoration of ecosystem health;
- Share: promoting asset sharing, promoting reuse and second-hand use, promoting life extension through design for durability and upgradeability;
- Optimise: allowing growth in production performance and efficiency, promoting the removal of waste in production and supply chains, leveraging the use of big data and automation;
- Loop: encouraging the remanufacturing of products or components, encouraging the recycling of materials, expanding the scale of waste recovery and resource reuse;
- Virtualise: encouraging indirect dematerialisation;
- Exchange: promoting the replacement of old materials with advanced materials, promoting the application of new technologies, and promoting the choice of new products and services (capacity for innovation).

1.3. Technologies that support the circularity of activities based on Industry 5.0/4.0 tools

While the Industry 4.0 paradigm focused on the inclusion of digital production equipment into the manufacturing process, Industry 5.0 emphasises the human factor to provide decision-making or physical actions at decision nodes in the otherwise automated process flow (Turner et al., 2022). Industry 5.0 emphasises the aspects of environmental awareness and sustainability (Trstenjak et al., 2023). This also suggests the value-driven aspect of Industry 5.0 compared to the technology-driven Industry 4.0, which is meant to be the main difference between Industries 4.0 and 5.0 (Xu et al., 2021; Kemendi et al., 2022). Industry 5.0 is characterised by sustainability, human-centricity and resilience (European Commission, 2021a). This goes beyond the Industry 4.0 approach, which was about improving efficiency and productivity due to emerging technologies.

Digital technologies have an enabling role in operationalising the circular economy (CE) transition. A circular economy embodies the shift from a linear to a circular economy and focuses on decreasing the environmental pressure, e.g., material extraction and waste disposal (Cagno et al., 2021). Unfortunately, despite the supportive role of digitalisation in the development of the circular economy, it negatively impacts the environment through increased energy consumption (Islam et al., 2023; Avom et al., 2020) and an increase in the amount of e-waste generated (Shahabuddin et al., 2023; Vishwakarma et al., 2022). Thus, ICT is not only an important but also a problematic tool in the pursuit of sustainable development (Charfeddine & Umlai, 2023). The approach of circular manufacturing fundamentally reshapes the consumption of resources. Therefore,

Tab. 1. Main characteristics of enabling technologies

Enabling technology	Main characteristics
Cyber-Physical Systems (CPSs) and Cyber-Physical Production systems (CPPS)	Real-time data processing and information feedback, computational capability, decision-making capability; the concept that the virtual world and the physical world can be merged by CPS; Industry 4.0 uses CPS technology to build a CPPS platform to enable equipment in a smart factory to be more intelligent and create better production conditions enabling smart production
Internet of Things (IoT)	Data sharing enhances supply chain transparency; aims to solve communication problems between all objects and systems in a factory; IoT includes radio frequency identification (RFID) devices, infrared sensors, global positioning systems, laser scanners and other information sensing devices which can be connected to internet to an agreed protocol
Big Data Analysis (BDA)	Analytics based on large data set in a short period; facilitate and support the decision-making process (data-driven insights), e.g., in manufacturing, microprocessors may be installed on machines to collect production data, and sensors and microprocessors generate a huge source of data with a size beyond the traditional scale
Cybersecurity and Blockchain (CYB)	Ability to assure transparency and the protection of the cyber environment, e.g., secure and reliable communications, identity and access management of machines and users; can support circular purchasing and design, etc.
Additive Manufacturing (AM), esp. 3D printing	Enables direct production of 3D models, used for small batches with a high degree of customisation, shorter time-to-market and high production flexibility; ability to build parts with geometrical and material complexity not feasible with traditional manufacturing helps to reduce waste (e.g., by producing parts on demand) and favour the use of recovered materials instead of virgin raw materials
Artificial Intelligence (AI)	Cognitive science and research areas such as robotics, machine learning, natural language processing, image processing, artificial vision, etc., can support circular design, procurement, resource efficiency, waste management, and reverse logistics
Simulation (SIM)	Decision-making support; the only practical way to test models; reproduction of a system in an experimental model; potential for tracing and predicting the material flow along the supply chain, crucial for disassembly activities
Robotics (RB)	Help with the automation of the production process; robots are developing (more autonomous, flexible and cooperative; embedded intelligence can allow them to learn from human activities; collaborative robots (cobots) and human–robot interaction make work with humans possible)
Virtual Reality (VR) and Augmented Reality (AR)	Support the virtualisation strategy; VR provides a simulation tool for the recreation of a real-life environment; AR has progressed in applications to combine digital elements with real-world actions. VAR allows for simulating real situations, e.g., to train workers, avoid dangerous situations, and improve decision-making
Horizontal and vertical system integration	The realisation of truly automated and integrated value chains; can facilitate access to data, in particular allow collaboration among different stakeholders, offers opportunities for recycling activities and the redesign of products and processes
Cloud computing (CLOUD) technology	Allows the storage and sharing of data between stakeholders along the supply chain, the potential to promote collaboration; allows access from different devices; the model provides services to the user including software, hardware, platforms and other IT infrastructure resources

Source: (Neri et al., 2023; Sun & Wang, 2022; Laskurain-Iturbe et al., 2021; Yang & Gu, 2021; Rüssmann et al., 2015; García & García, 2019; Zhong et al., 2017; Zhou et al., 2015).

the implementation of circular manufacturing requires an integrated approach to manage the resources to realise the reduce, reuse, recycle, and recover principles. All this can be enforced through sound technological background. Following Laskurain-Iturbe et al. (2021), it was assumed that the outline of Industry 4.0 technologies looks as follows: Additive Manufacturing (AM), Artificial Intelligence (AI), Artificial Vision (AV), Big Data and Advanced Analyses (BDAA), Cybersecurity (CS), Internet of Things (IoT), Robotics (RB) and Virtual and Augmented Reality (VAR).

When it was first launched in 2011, there were nine pillars of Industry 4.0, i.e., cyber-physical systems (CPSs, the core of Industry 4.0), Internet of Things (IoT), Big data, 3D printing (otherwise known as additive manufacturing), robotics, simulation, augmented reality, cloud computing and cyber security (Yang & Gu, 2021). These pillars are capable of fully transforming the production flow. For example, Industry 4.0, industrial IoT, cloud computing, Big Data analytics and customer profiling, and cyber security can be considered as the most relevant enabling technologies for Supply Chain Management-Marketing (SCM-M) integration (Ardito et al., 2019). The circular economy practices can be enabled by adopting Industry 4.0 technologies. This issue is more challenging for small and medium-sized enterprises than for larger firms due to more limited resources and different characteristics (Neri et al., 2023). Table 1 shows the main characteristics of enabling technologies.

The Industry 4.0 era can be described as the era of intelligent manufacturing systems where manufacturing technologies are transformed by cyber-physical systems, the IoT and cloud computing (Zhong et al., 2017). Jafari et al. (2022) highlighted two major concepts: IoT and CPS. Cyber-physical systems are described as "a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities" (Baheti & Gill, 2011). Industry 4.0 technologies support companies in better circularity. In particular, most evidence shows the positive impact of additive manufacturing and robotics (Laskurain-Iturbe et al., 2021). The most important Industry 4.0 enablers for a cleaner production and circular economy within the context of business ethics are "Technical Capability", "Security and Safety", "Policy and Regulation", "System Flexibility", "Education and Participation", and "Support and Maintenance" (Shayganmehr et al., 2021).

Industry 5.0 puts the human-centric approach at the centre of the production process (Atif, 2023). An independent expert report about the results of a workshop with Europe's technology leaders pointed out that the enabling technologies for Industry 5.0 are a set of complex systems that combine technologies and can only unfold with others as part of systems and technological frameworks. The corresponding categories are:

- Individualised human-machine-interaction: technologies that interconnect and combine the strengths of humans and machines (technologies that support humans in physical and cognitive tasks, e.g., augmented, virtual or mixed reality technologies, collaborative robots ("cobots"), technologies for matching the strengths of Artificial Intelligence and the human brain; etc.).
- Bio-inspired technologies and smart materials allow materials with embedded sensors and enhanced features while being recyclable.
- Digital twins and simulation, real-time-based digital twins and simulation: to model entire systems (optimise production, test products and processes and detect possible harmful effects, e.g., Digital twins of products and processes, virtual simulation and testing of products and processes).
- Data transmission, storage, and analysis technologies (e.g., cyber security/safe cloud IT infrastructure, big data management) that are able to handle data and system interoperability.
- Artificial intelligence, e.g., to detect causalities in complex, dynamic systems, leading to actionable intelligence.
- Technologies for energy efficiency, renewables, storage and trustworthy autonomy, e.g., in support of the energy usage of the above-named technologies (European Commission, Müller, 2020).

The list of key enablers of Industry 5.0 can be grouped as follows according to Trstenjak et al. (2023) with similar content to that of the above list:

- Human-centred approach (human knowledge and skills as one of the most treasurable resources and competitive advantages).
- Flexibility and modularity (digital twins, self-optimisation, and collaborative robots).
- Human factors, ergonomics, well-being and ethical technology (worker motivation, improve workers' health and minimise the impact of stress-related diseases which lead to absence from work).

- Innovation management (market competitiveness, flexibility and adjustment to the demands and needs of the market, reducing production costs, increasing product quality and shortening time-to-market).
- Green and sustainable manufacturing (use of sustainable energy sources and increase of energy efficiency; circular economy concept).

Environmentally sustainable enterprises use advanced technologies and transform their production flow, avoiding environmental degradation (Ahmad & Satrovic, 2023; Arshad et al., 2023; Charfeddine & Umlai, 2023). The technologies must be accepted and trusted, and people must be trained to use them. Sustainable enterprises represent a true contribution to corporate social responsibility. All this suggests trustworthiness and represents a layer of ethical business practices which can attract customers.

The use of Industry 5.0 technologies translates into increased circular manufacturing. Unfortunately, in the area of waste management, the risks associated with the implementation of Industry 5.0 involve an increase in the volume of generated e-waste (De Giovanni, 2023). Accordingly, the research question is as follows:

Q2: Is there a correlation between the level of circular manufacturing and the amount of generated e-waste?

2. Research methods

Data from the Eurostat database (2023) were analysed. The set of variables is presented in Table 2.

To examine the level of circularity manufacturing, a synthetic measure of development was estimated, which included backfilling operations in addition to recycling operations. It was assumed that the various countries of the European Union are open economies in which waste is imported and exported, i.e., it is collected in one country and then processed and recovered in another. The data used to estimate the synthetic measure represent the flows of materials used in the economy and discharged into the environment or reintroduced into economic processing. The data concerns three categories related to flows in the economy: inputs into the economy, processed materials, and outputs from the economy.

Data in the category of inputs into the economy include the flow of products from the rest of the world's economy into the domestic economy. This flow also includes waste sent for processing (e.g., conversion into recyclable materials) in the receiving country. This category also includes quantities of material resources extracted from the environment by production units in the country, especially materials such as biomass metal ores, non-metallic minerals and fossil energy materials/carriers. Imports, together

Tab. 2. Set of variables

Category	Variable symbol	Variable name	Variable character (S – stimulant, D – destimulant)
Inputs into the economy	IMP_T	Imports of waste for recovery — recycling	S
	EIMP_T	Imports excluding imports of waste for recovery — recycling	S
	DE_T	Domestic extraction	D
Processed materials	MAC	Material accumulation	D
	WTR_T	Waste treatment recovery — recycling	S
	WTB_T	Waste treatment recovery — backfilling	S
Outputs from the economy	EXP_T	Exports of waste for recovery — recycling	S
	EEXP_T	Exports excluding exports of waste for recovery — recycling	S
	EMI	Emissions	D
	DFL	Dissipative flows	D
	WTD_T	Waste treatment disposal — landfill	D
Waste electrical and electronic equipment	EEPM	Waste arising only from separate collection of EEE — products put on the market	D
	WEER	Waste arising only from separate collection of EEE — recovery	S
	WEERT	Waste arising only from separate collection of EEE — recovery/ waste arising only from separate collection of EEE — products put on the market	S

with domestic extraction, are direct material inputs to the economy.

Processed materials were defined as the sum of accumulated material that is collected before it is used and secondary materials, i.e., recycled and backfilled materials. The processed materials can be exported or used in the country. According to Eurostat's methodology, it was assumed that only the flows of recycling and pit filling close the loop of the circular economy (circular economy — material flows, 2022).

The economy's results included the weight of exported products, total emissions reflecting solid, liquid and gaseous material flows, dissipative flows, i.e., materials dispersed into the environment as an intentional or unavoidable consequence of product use, and the amount of waste landfilled.

A linear ordering method used in the area of multidimensional data analysis was applied to assess the level of circular manufacturing. This is because it was assumed that this potential can be expressed by a synthetic variable, which consists of the effects of each country's actions in the use of material streams in the production process. Twenty-seven countries of the European Union were covered in the study. They were assumed to be regions characterised by the peculiarities of the production process organisation, as well as by different social and cultural conditions shaping the pro-ecological awareness of the organisation of these processes. It was also assumed that the effects achieved in a given country in the scope analysed are a direct result of the companies' activities. This is because the synthetic variable considers variables that determine the level of effects achieved through the implementation of sustainability-oriented measures in companies, as defined by all kinds of interstate and national policies. European Union countries (characterised by a number of variables determining the level of circular manufacturing) were therefore ordered in terms of preference (dominance) relationships. The synthetic variable was determined for the years 2013–2021. The determined synthetic variable was used to create a ranking of European Union countries according to the level of circular manufacturing for each year. It was performed in the following steps:

1. A matrix of diagnostic features observed for each country of the European Union was constructed x_{ij}, i=1, 2, …, *27*; j=1, 2, …, *11* (n — the number of countries, m — the number of variables). To make the data more comparable, they were presented as intensity indicators (tons per capita).

2. The variables were unitarised to free their titers and standardise the orders of the values they took, according to the formula:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j},$$

$$(i=1, 2, \ldots, 27;\ j=1, 2, \ldots, 11) \qquad (1)$$

where:

z_{ij} — the standardised value of variable X_j,

$\bar{x}_j$ — arithmetic average of variable X_j,

s_j — standard deviation of variable X_j.

3. Euclidean distances of individual objects from the model object were determined:

$$d_{i0} = \sqrt{\sum_{j=1}^{m}(z_{ij} - z_{0j})^2} \qquad (i = 1, \ldots, 27), \quad (2)$$

where

$z_{0j} = \max_i z_{ij}$, for stimulant variables and

$z_{0j} = \min_i z_{ij}$, for destimulant variables.

To measure the distance, it was assumed that all variables affected the level of the analysed phenomenon with equal force.

4. A measure of development was estimated for each object according to the formula:

$$m_i = 1 - \frac{d_{i0}}{d_0} \qquad (i = 1, \ldots, 27). \qquad (3)$$

Where:

d_0 — the distance between the pattern and anti-pattern of development:

$$d_0 = \sqrt{\sum_{j=1}^{m}(z_{ij} - z_{\_0j})^2} \qquad (i = 1, \ldots, 27), \quad (4)$$

where $z_{\_0j} = \min_i z_{ij}$, for stimulant variables and

$z_{\_0j} = \max_i z_{ij}$, for destimulant variables.

The level of use of Industry 5.0 technologies was expressed in the variable "Waste electrical and electronic equipment", and in particular in the variable "Waste arising only from separate collection of electrical and electronic equipment (EEE) — Products put on the market". This is because it was assumed that Industry 5.0 technologies in the context of the circular economy and material flows are expected to reduce waste rather than increase effectiveness (Dwivedi et al., 2023; Voulgaridis et al., 2022). Because apart from waste generated in the current production and consumption, previously stored waste is used in the production process, the analysis also covered the variable expressing the relationship of "Waste arising only from separate collection of EEE — recovery/waste arising only from separate collection of EEE — products put on the market". This relationship expresses the balance between the amount of waste that can be reintroduced into the production system or, more broadly, into the economic system and the amount of waste that remains in the environment (does not return to the production process).

The values of variables were determined for each year of the 2013–2021 period, and the dynamics of changes in their formation were examined. For this purpose, the estimations focused on the index of dynamics for 2021 in relation to 2013 and the average annual rate of change. The analysis of the dynamics made it possible to identify trends in the level of circular manufacturing and the level of e-waste during the period under study.

Also, correlations were examined between the level of circular manufacturing and the amount of e-waste and between the dynamics of change for the variables. The correlation analysis made it possible to check whether increasing the effectiveness of circular manufacturing efforts translates into reduced generation of e-waste, which would be a positive effect of using information technology.

Ranges were built based on the dynamics measures for the measure of development and the amount of e-waste introduced into the market class. They were used to create a systematic division of the country according to conditions for developing environmentally sustainable enterprises and the constancy of this development (the dynamics of change of the synthetic measure). The dynamics of the amount of e-waste recovered provided the basis for dividing countries according to the criterion of the positive use of information technology in creating circular manufacturing cycles. It was recognised that:

- The value of the first quartile indicates economies with poor conditions for the development of environmentally sustainable enterprises, the value of the second quartile — average conditions, and the value of the third quartile — good conditions.
- A measure of dynamics in the range from 95 % to 105 % was considered indicative of a constant situation in the level of circular manufacturing (thereby, constant situation in the development of environmentally sustainable enterprises) and the amount of e-waste, whereas a measure lower than 95 % indicated regression in the level of circular manufacturing and a positive effect in terms of the amount of e-waste, and a value higher than 105 % indicated progress in the level of circular manufacturing and a negative effect in terms of the amount of e-waste.

3. Research results

Table 3 presents the value of the synthetic development measure for the European Union countries in 2013–2021. The highest level of circular manufacturing in all analysed years was observed for Luxembourg. The next three positions were taken by the Netherlands, Belgium and Slovenia. The measure of development for Luxembourg far exceeded the others, indicating that the country can be considered a model.

Table 4 presents waste arising only from a separate collection of EEE — products put on the market for individual European Union countries in the years 2013–2021.

The amount of waste arising only from separate EEE collection reintroduced into economic processing increases per capita with the industrial and economic development of the country.

Similar patterns are observed for the amount of waste arising only from separate collection of EEE recovered — the amount increases with the industrial and economic development of a country (Table 5).

Table 6 shows the dynamics of measures for the selected variables. An increase in the development measure in 2021 compared to 2013 was observed only for two countries of the European Union (Bulgaria and Slovenia), which means that only these countries had an average annual increase in the level of circular manufacturing in 2013–2021. Positive trends are observed for the amount of e-waste recovered; only Portugal and Sweden saw an average annual decrease in e-waste recovery, but it was insig-

Tab. 3. Results of linear classification — a measure of the development of the European Union countries according to the level of circularity manufacturing in 2013–2021

Countries	Measure of development in the year								
	2013	2014	2015	2016	2017	2018	2019	2020	2021
Luxembourg	0.692	0.648	0.612	0.626	0.625	0.638	0.622	0.610	0.605
Netherlands	0.522	0.516	0.480	0.478	0.483	0.482	0.490	0.478	0.498
Belgium	0.483	0.474	0.442	0.435	0.434	0.437	0.451	0.468	0.469
Slovenia	0.443	0.433	0.408	0.396	0.417	0.435	0.437	0.435	0.446
Austria	0.401	0.386	0.366	0.347	0.349	0.351	0.363	0.372	0.378
Malta	0.369	0.350	0.332	0.323	0.343	0.354	0.354	0.354	0.359
Czechia	0.358	0.339	0.314	0.309	0.318	0.331	0.339	0.344	0.354
Latvia	0.364	0.333	0.309	0.308	0.302	0.309	0.314	0.327	0.339
Slovakia	0.353	0.328	0.303	0.300	0.302	0.306	0.322	0.330	0.339
Germany	0.368	0.357	0.334	0.325	0.319	0.322	0.329	0.315	0.329
Lithuania	0.352	0.334	0.314	0.310	0.305	0.309	0.313	0.318	0.323
Sweden	0.365	0.349	0.328	0.326	0.310	0.304	0.305	0.312	0.316
Denmark	0.344	0.319	0.285	0.278	0.284	0.294	0.296	0.299	0.314
France	0.364	0.349	0.324	0.314	0.305	0.308	0.311	0.310	0.313
Croatia	0.314	0.299	0.274	0.271	0.270	0.273	0.282	0.297	0.306
Italy	0.332	0.316	0.292	0.286	0.283	0.286	0.291	0.296	0.299
Hungary	0.325	0.296	0.272	0.271	0.272	0.268	0.277	0.296	0.296
Poland	0.329	0.319	0.293	0.276	0.265	0.264	0.285	0.276	0.295
Spain	0.333	0.319	0.291	0.280	0.283	0.287	0.287	0.284	0.293
Estonia	0.331	0.287	0.256	0.258	0.247	0.250	0.270	0.299	0.291
Greece	0.301	0.283	0.254	0.251	0.253	0.265	0.269	0.275	0.285
Cyprus	0.316	0.297	0.280	0.272	0.255	0.259	0.248	0.259	0.266
Portugal	0.308	0.276	0.254	0.255	0.246	0.248	0.253	0.264	0.264
Bulgaria	0.240	0.216	0.202	0.227	0.219	0.217	0.228	0.232	0.253
Ireland	0.233	0.219	0.202	0.192	0.187	0.193	0.188	0.197	0.204
Finland	0.233	0.239	0.216	0.193	0.206	0.203	0.218	0.205	0.196
Romania	0.275	0.247	0.202	0.198	0.204	0.201	0.175	0.169	0.184

nificant, i.e., 0.84 % for Portugal and 3.09 % for Sweden. The volume of e-waste put on the market in the case of these two countries was unfortunately higher in 2021 compared to 2013. Generally, an average annual increase in the amount of e-waste recovered is observed for all European Union countries, with the exception of Luxemburg and Malta. However, in countries such as Denmark, Germany, Italy, Lithuania, Hungary, Netherlands and Romania, the volume of waste put on the market is growing faster than the amount of waste recovered.

Pearson's linear correlation coefficients were estimated to determine the relationship between the synthetic measure of development and the amount of e-waste put on the market (Table 7) and the dynamics of change for these two measures.

The values of the correlation coefficients do not confirm the existence of a relationship between the

Tab. 4. Waste arising only from a separate collection of EEE — products put on the market of the European Union countries in 2013–2021

Countries	Waste arising only from separate collection of EEE — products put on the market (kilograms per capita)								
	2013	2014	2015	2016	2017	2018	2019	2020	2021
Bulgaria	7.8	9.08	9.47	10.14	10.58	11.65	12.78	12.57	13.46
Latvia	8.86	9.2	9.68	9.56	11.85	12.59	14.42	14.89	16.04
Lithuania	9.31	10.75	10.69	11.19	11.87	12.7	14.13	15.03	16.09
Cyprus	11.15	10.29	11.52	7.21	13.37	13.8	13.92	15.49	16.23
Greece	11.37	12.8	11.56	12.1	12.5	13.59	15.54	16.06	16.87
Slovakia	8.51	9.84	9.72	12.12	12.55	13.56	14.84	15.72	17.16
Croatia	9.38	9.25	10.62	12.01	13.17	14.99	15.14	16.43	17.8
Malta	34.2	39.44	29.7	22.48	23.91	21.4	23.14	21.06	19.65
Romania	6.85	7.01	8.49	10.19	12.15	13.41	15.34	17.54	20.07
Luxembourg	21.68	21.68	20.66	20.34	21.38	20.99	20.59	20.55	20.39
Portugal	11.66	11.72	12.59	13.33	15.34	17.6	19.82	20.62	22.37
Slovenia	13.83	14.75	15.22	17.09	16.18	17.44	20.07	21.07	22.38
Spain	10.9	11.99	12.99	13.48	14.32	15.44	18.43	21.21	23.33
Czechia	17.3	17.04	17.26	17.74	19.21	18.52	22.14	24.6	25.87
Ireland	18.39	19.21	18.37	20.29	22.56	20.83	22.71	24.94	26.05
Estonia	10.6	11.52	11.79	12.09	12.56	14.46	17.22	23.52	26.36
Italy	14.06	14.54	15.02	16.69	16.96	24.54	23.81	26.26	28.71
Hungary	8.08	9.43	10.57	11.78	13.65	23.53	24.45	24.91	29.26
Finland	25.3	23.1	21.54	22.31	22.57	24.08	22.92	28.79	29.33
Sweden	25.28	24.54	26.22	26.1	27.71	28.31	30.58	28.93	29.49
Belgium	24.19	23.23	23.86	24.52	25.69	27.23	29.68	29.01	29.77
Poland	12.78	13.65	13.87	15.36	15.99	17.39	20.86	27.29	30.41
Austria	18.38	19.34	21.6	23.8	24.02	26.41	27.14	30.36	32.62
France	23.64	23.44	25.19	26.2	28.1	28.72	31.08	32.26	33.73
Germany	19.95	21.16	23.23	23.78	25.18	28.65	31.17	34.25	37.00
Denmark	24.66	27.	27.24	27.69	29.85	30.35	35.61	39.25	41.94
Netherlands	18.21	18.97	20.23	21.82	24.37	28.56	36.82	43.29	48.99

level of circular manufacturing and the amount of e-waste put on the market. None of the correlation coefficients proved statistically significant (at the significance level of $p<0.1$). Also, the correlation coefficient between the average annual rate of change in the synthetic development measure and the average annual rate of change in the amount of e-waste of -0.23812 proved statistically insignificant (at the significance level of $p<0.1$).

It was assumed that for economies for which the average annual rate of change for the measure of development was in the range (-5 %; 5 %), invariant conditions for the development of environmentally sustainable enterprises were observed. For all countries, the average annual rate of change was within the range, which means that all countries were characterised by a fairly constant level of circular manufacturing and, thereby, a constant level of development of

Tab. 5. Waste arising only from separate collection of EEE —Recovery of the European Union countries in 2013–2021

Countries	Waste arising only from separate collection of EEE — recovery (kilograms per capita)								
	2013	2014	2015	2016	2017	2018	2019	2020	2021
Portugal	4.53	4.99	5.59	6.15	6.18	6.51	4.37	4.27	4.23
Romania	1.5	1.47	1.52	2.03	2.29	2.87	3.27	3.72	4.24
Malta	4.01	4.38	2.9	5.55	4.55	4.82	5.09	4.27	4.31
Lithuania	4.16	6.18	4.87	3.98	4.15	4.46	5.12	5.16	5.32
Greece	3.29	3.5	4.06	4.6	4.37	4.7	5.33	5.07	5.39
Latvia	2.17	2.23	2.03	2.19	3.89	4.25	5.01	5.13	5.8
Cyprus	2.13	2.4	3.18	2.78	4.28	3.45	3.97	5.2	5.91
Italy	6.47	4.41	5.01	5.3	5.8	6.13	6.6	7.23	7.35
Slovenia	2.23	4.38	4.52	5.68	6.11	6.17	6.49	6.41	7.45
Hungary	4.46	4.67	4.71	5.14	5.54	6.01	7.26	7.88	8.55
Spain	2.79	3.21	4.07	5.02	5.44	6.4	6.65	7.45	8.57
Slovakia	3.68	3.87	3.96	4.76	4.99	5.24	6.53	7.93	8.85
Luxembourg	8.91	9.27	9.62	9.96	9.7	9.5	9.32	9.66	9.77
Estonia	2.5	4.2	5.21	6.29	6.65	7.23	7.68	8.68	10.37
Bulgaria	4.08	5.06	7.56	7.21	6.79	6.47	8.21	9.36	10.54
Croatia	3.53	3.59	5.23	8.98	8.43	9.26	9.15	9.6	11.07
Czechia	4.72	4.8	5.94	9.27	8.97	7.61	9.09	9.97	11.09
Poland	3.44	3.38	3.69	5.06	5.39	5.94	9.67	9.71	11.26
Belgium	9.25	8.87	9.15	9.36	9.35	10.	10.41	11.41	11.76
Netherlands	6.68	8.12	8.21	8.7	9.31	9.64	9.31	11.24	12.11
France	6.31	7.06	8.31	9.76	9.95	10.05	10.83	11.23	12.19
Ireland	8.	8.31	9.69	10.42	9.88	11.45	11.73	11.92	12.62
Germany	8.52	8.52	7.98	9.19	9.82	10.01	11.09	12.25	12.9
Sweden	16.89	13.78	13.46	15.09	12.91	13.04	14.83	13.56	13.14
Denmark	11.49	11.48	11.74	11.75	11.24	11.1	11.77	12.93	13.15
Finland	10.36	10.94	10.89	10.29	11.17	11.44	12.71	15.19	16.04
Austria	8.13	8.4	8.57	8.9	12.36	12.22	14.07	14.81	16.13

environmentally sustainable enterprises. Fig. 1 shows a systematic breakdown of the country according to the conditions for the development of environmentally sustainable enterprises and the e-waste effect. The figure also indicates the effects of changes in the level of e-waste put on the market based on the average annual rate of change.

Most countries have average conditions for the development of environmentally sustainable businesses, but at the same time, they show negative trends in the volume of e-waste generated. Given that an increase in e-waste means an increase in the level of digitisation, including digitisation of enterprises, a high level of circular manufacturing and, therefore, good conditions for the development of environmentally friendly enterprises can be expected. Unfortunately, assuming that all countries show a stable level of circular manufacturing (slight changes in the synthetic measure of development in 2013–2021), it can be argued that the development of IT infrastructure

Tab. 6. Change dynamics for the selected variables in the years 2013–2021

Countries	Dynamics index for 2021 (2013 = 100%)				Average annual rate of change			
	Measure of development	EEEPM	WEER	WEERT	Measure of development	EEEPM	WEER	WEERT
Belgium	97%	123%	127%	103%	-0.39%	3.04%	2.63%	0.40%
Bulgaria	106%	173%	258%	150%	0.71%	12.59%	7.05%	5.17%
Czechia	99%	150%	235%	157%	-0.13%	11.27%	5.16%	5.82%
Denmark	91%	170%	114%	67%	-1.15%	1.70%	6.86%	-4.83%
Germany	89%	185%	151%	82%	-1.40%	5.32%	8.03%	-2.50%
Estonia	88%	249%	415%	167%	-1.59%	19.46%	12.06%	6.61%
Ireland	88%	142%	158%	111%	-1.64%	5.86%	4.45%	1.35%
Greece	95%	148%	164%	110%	-0.66%	6.37%	5.06%	1.25%
Spain	88%	214%	307%	144%	-1.59%	15.06%	9.97%	4.63%
France	86%	143%	193%	135%	-1.87%	8.58%	4.54%	3.87%
Croatia	97%	190%	314%	165%	-0.33%	15.36%	8.34%	6.49%
Italy	90%	204%	114%	56%	-1.33%	1.60%	9.33%	-7.08%
Cyprus	84%	146%	277%	190%	-2.14%	13.60%	4.81%	8.39%
Latvia	93%	181%	267%	148%	-0.87%	13.08%	7.70%	5.00%
Lithuania	92%	173%	128%	74%	-1.06%	3.13%	7.08%	-3.69%
Luxembourg	87%	94%	110%	117%	-1.67%	1.16%	-0.76%	1.94%
Hungary	91%	362%	192%	53%	-1.17%	8.47%	17.45%	-7.64%
Malta	97%	57%	107%	187%	-0.32%	0.90%	-6.69%	8.14%
Netherlands	95%	269%	181%	67%	-0.59%	7.72%	13.17%	-4.82%
Austria	94%	177%	198%	112%	-0.76%	8.95%	7.43%	1.41%
Poland	90%	238%	327%	138%	-1.35%	15.98%	11.45%	4.07%
Portugal	86%	192%	93%	49%	-1.91%	-0.84%	8.49%	-8.60%
Romania	67%	293%	282%	96%	-4.89%	13.86%	14.38%	-0.46%
Slovenia	101%	162%	334%	207%	0.07%	16.28%	6.20%	9.49%
Slovakia	96%	202%	240%	119%	-0.52%	11.59%	9.16%	2.23%
Finland	84%	116%	155%	134%	-2.17%	5.62%	1.86%	3.69%
Sweden	87%	117%	78%	67%	-1.78%	-3.09%	1.95%	-4.94%

Tab. 7. Correlation coefficients

Years	Correlation coefficient between the synthetic measure of development and the amount of e-waste put on the market
2013	-0.03254
2014	0.01772
2015	-0.12553
2016	-0.07153
2017	-0.05261
2018	-0.07122
2019	-0.11140
2020	-0.05592
2021	-0.05712

		The conditions for the development of environmentally sustainable enterprises		
		BAD	AVERAGE	GOOD
E-WASTE EFFECT	NEGATIVE	Bulgaria, Greece, Portugal, Romania	Denmark, Germany, Estonia, Spain, Croatia, Italy, Latvia, Lithuania, Hungary, Poland, Slovakia	Czechia, Netherlands, Austria, Slovenia
	AVERAGE	Ireland, Cyprus, Finland	France, Sweden	Belgium, Luxembourg
	POSITIVE			Malta

Fig. 1. Systematic breakdown of the country according to the conditions for the development of environmentally sustainable enterprises and the e-waste effect

does not translate into an increase in the level of circular manufacturing. Positive trends are observed for Malta, Belgium and Luxembourg, which create good conditions for the development of environmentally sustainable businesses and, at the same time, introduce a smaller or fairly constant amount of e-waste to the market. A large increase in e-waste can be observed in Bulgaria, Greece, Portugal and Romania, but unfortunately, the increase is not matched by a high level of circular manufacturing.

4. Discussion of the results

Research indicates that digitalising all types of activities promotes circular e-waste management, including prevention, collection, and treatment (Bagwan, 2024). Unfortunately, the amount of e-waste continues to grow, becoming an environmental problem. Therefore, it can be concluded that, on the one hand, information and communication technologies foster closed production cycles, and on the other hand, they are a source of pollution, including e-waste. A lot of research is devoted to the issue of linking the Industrial Revolution (in particular Industry 4.0) to sustainable development, including the reduction of the negative impact of economic activities on the environment. These studies mainly focus on the problem of whether and how Industry 4.0 technologies support sustainable development (Calabrese et al., 2023; Piccarozzi et al., 2023). In this article, research is also devoted to the relationship between information technologies and environmental sustainability, except that it analyses variables that can underpin the measurement of circular manufacturing and the magnitude of e-waste streams as an effect of Industry 5.0 implementation.

The article analyses the European Union economies according to the level of circular manufacturing and its dynamics. Measuring the effects of circular manufacturing can be a problem. Although the waste reduction effect of circular manufacturing is measurable, it is difficult to consider it as a measure of circular manufacturing or, more broadly, the circular economy. The level of circular manufacturing is expressed in terms of a synthetic measure consisting of variables representing the flows of materials used in the economy and discharged into the environment or reintroduced into economic processing. This way of measuring circular manufacturing level differs from the ways proposed in the literature. The basic measure of the circularity of the economy in the European Union is the circular material use rate (CMUR). It is defined as the ratio of the amount of waste recycled at domestic recovery facilities minus the amount of imported waste for recovery plus the amount of exported waste intended for recovery abroad to the amount of materials consumed. Considering CMUR, the only waste treatment operations contributing to the circular economy are those producing recyclable materials. These operations include recycling only and do not include backfilling. Furthermore, CMUR does not involve waste imported to be recovered domestically.

The European Commission identifies ten key indicators of a circular economy relating to different stages of product lifecycle and aspects of competitiveness. The indicators are divided into four groups: (1) production and consumption, (2) waste management, (3) recyclable materials, and (4) competitiveness and innovation (Communication from the Commission…, 2018). It should be noted, however, that the links between some indicators and the circular economy are indirect, even though they provide information on the circularity of the economy.

The literature offers many indicators relating to circularity at the microeconomic level. A review of 40 indicators was offered by Syu et al. (2022), five of which were checked for suitability in a manufacturing company:

- Material Reutilisation Score (MRS) — an indicator determining the share of secondary and recyclable or biodegradable materials in the product;
- Circular Economic Value (CEV) — an indicator determining the level of consumption of materials and energy in the production process;
- Product-Level Circularity Metric (PLCM) — an indicator representing the ratio of recirculated economic value to total product value;
- Quantitative Indicators and Value Assessment (QIVA) — an indicator determining areas of interventions in manufacturing processes based on production data, e.g., the volume of material flows feeding the process, their characteristics, costs associated with environmental management;
- Material Circularity Indicator (MCI) — an indicator determining the degree to which the linear flow should be minimised and the circular flow maximised.

However, the listed indicators only allow monitoring of selected material streams in the production process of enterprises, e.g., material and energy consumption, without considering the complexity and comprehensiveness of circular flows. The disadvantage of these indicators is the selective perception of circular processes, as they only consider the streams that constitute the input to the production system or its output. The synthetic measure of development proposed in the article allows circular manufacturing to be measured by considering the flows of all materials used in the economy and discharged into the environment or reintroduced into economic processing (research question Q1). This is obviously not a perfect measure. It does not show, e.g., the negative environmental impact of materials reintroduced into the production process (as a result of processing operations). It also does not indicate the correct proportions between input and output to the system.

Scrap electrical and electronic equipment is the fastest-growing waste category, becoming a massive environmental problem. Reducing the amount of generated e-waste seems impossible due to advances in technology and ever-increasing demands for digitisation (Dixit et al., 2023). The high value of waste arising only from separate EEE collection, which is reintroduced into economic processing per capita in industrialised and economically developed countries, is, on the one hand, a manifestation of positive processes with regard to the promotion of circular manufacturing in the context of the use of information technology, because it is indicative of:

- high environmental awareness of the society,
- feeding the production process with non-natural resources,
- protection of valuable resources,
- taking actions that are most beneficial from the point of view of the waste hierarchy,
- digitisation development.

On the other hand, however, e-waste is seen as a source of toxic substances that seriously threaten the environment. From an environmental perspective, the amount of electronic waste introduced into processing should be as low as possible, provided that this low value does not result from improper disposal of this waste type. Its volume, however, is higher for developed countries. This may be due to the higher availability and use of electronic equipment, which, therefore, indicates that production processes are supported by information technology.

Unfortunately, no statistically significant correlations have been observed between the level of circular manufacturing and the amount of e-waste put on the market in the European Union countries (research question Q2). These findings support research showing that sustainable practices do not significantly mitigate the impact of Industry 4.0 technologies on sustainable performance (Yavuz et al., 2023). That breeds the need for an integrated measurement system to monitor and evaluate the sustainable development of new technologies, also, and perhaps especially, in the context of the dynamics of Industry 5.0 technologies (Ghobakhloo et al., 2023). Industry 5.0 stakeholders should be able to assess both its complexity and dynamics to implement modern information solutions in line with broader sustainability goals.

The vast majority of countries, however, show an average annual increase in e-waste (Fig. 1), which is a negative trend from an environmental perspective. It is assumed that revenues from e-waste recovery will open up prospects of ventures aimed at environmental benefits and the transition to a circular economy (Al-Salem et al., 2022). Unfortunately, the value of waste is still seen mainly in economic terms (Edirisinghe et al., 2023). Therefore, it is important to reduce waste by redefining its value in socio-ecological rather than monetary terms (Savini, 2023). Even more so, the creation of circular economic cycles does not lead to a reduction in either production or consumption, which means it does not reduce waste but increases the level of recovery. Therefore, it is necessary to find ways to reduce e-waste, mainly avoiding their generation.

Conclusions

The study was conducted to assess material flows in the production process reflecting the circular manufacturing level in the European Union countries and to investigate whether there is a relationship between the circular manufacturing level and the e-waste amount put on the market as an effect of implementing the Industry 5.0 technology. The level of circular manufacturing in the European Union countries was assessed, and the relationship of this level with the amount of generated e-waste was examined. A synthetic development measure, which considers material flows in the circular economy, was proposed to determine the circular manufacturing level.

Based on a synthetic development measure, the European Union countries were ordered according to the effects of activities in the use of material streams in the production process, in particular imports of waste for recovery and recycling, domestic extraction, material accumulation, waste recycling, waste backfilling, exports of waste for recovery and recycling, emissions, dissipative flows, and waste landfill. For all economies, the level of circular manufacturing was found to remain unchanged in the analysed 2013–2021 period. The level of use of Industry 5.0 technology is expressed in the amount of waste arising only from separate collection of EEE and put on the market. Industry 5.0 is a consequence of technological advances, digitisation and the need to instil environmentally friendly behaviour in manufacturers and consumers. Modern information technologies also support activities that will reduce the amount of waste going into the environment. Unfortunately, they are a source of waste, so their use should also be controlled in terms of environmental consequences. In the context of circular manufacturing, the use of Industry 5.0 technology should significantly reduce the amount of waste generated, including e-waste.

In addition, based on trends in the e-waste amount introduced into the market and the level of synthetic development measure, economies were broken down according to the effects on e-waste streams and conditions for developing environmentally sustainable businesses.

The research provided several practical and policy implications. First, companies should look for measures of the effect of implementing solutions that foster closed production cycles. The indicated synthetic measure of the circular manufacturing level considers material flows, which should result in lower consumption of production resources. Using it at the enterprise level will allow for observing trends in this area and diagnosing possible irregularities. It is also crucial to find a method to determine how implementing Industry 5.0 technology translates into these effects. Another important task is to change the way waste is viewed, as it should be considered primarily in social and environmental terms and not in economic terms. Enterprises mainly reach for methods related to the handling of waste already generated. They try to mitigate the environmental impact of their activities by subjecting waste to reuse and recycling processes. Such actions lead to restoring the use value of waste while giving it monetary value. However, the right action would be to avoid waste generation. Unfortunately, studies conducted indicate that the amount of waste per capita (especially e-waste) is increasing, especially in developed countries. This should be the impetus for efforts to avoid waste in general. Any waste poses a threat to the environment, as handling methods, even such as reuse and recycling, generate certain environmental and social consequences.

Second, government entities should promote cooperation among Industry 5.0 stakeholders, i.e., manufacturers, technology providers, the public and law-making entities in developing and implementing sustainability principles to create closed production cycles. The article points out the roles of material flows in the circular economy context. The stimulants and destimulants influencing volumes of individual material streams were identified through the proposed synthetic measure of the circular manufacturing level. This can be a guideline for individuals creating a political-administrative framework for sustainable development, and the circular economy in particular, in terms of planned guidelines. Creating incentives for using environmentally friendly solutions will help change companies' mindset towards implementing green solutions that favour the environment in various areas of their operations.

A limitation of the research is that it takes the level of e-waste volume to affect the implementation of the Industry 5.0 technology to increase the circular manufacturing level. It is a problem because the level applies to all e-waste generated in a country, not just that generated as a result of implementing Industry 5.0 technologies. Another problem is quantifying the level of application of Industry 5.0 technology in enterprises because it is a qualitative variable. It is also necessary to investigate relationships other than linear between the amount of e-waste (or, more broadly, the use level of Industry 5.0) and the circular manufacturing value. Another downside is the short analysis period of only nine years. Solutions, especially Industry 5.0, are only in the implementation phase, so the visible effects of technology implementation have yet to be seen, especially in terms of national economies. Therefore, the future research direction will be to analyse the effects of circular manufacturing in enterprises in the context of Industry 5.0 technologies implemented for this purpose using statistical regression models. In addition, analyses have been conducted at the level of European Union countries. Future research should focus on organisational networks. Creating a circular manufacturing system goes beyond the boundaries of a company and undermines established relational structures. Companies in a circular economy are seen as partners creating a value network, which means that the product supplier and the customer cannot be clearly separated as the customer can simultaneously become a supplier and thus change the power structure of the entire value chain (Mauss et al., 2023).

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