ISSN 2543-6597

Bialystok University of Technology
Faculty of Engineering Management

sciendo

International Society for Manufacturing, Service and Management Engineering

Engineering Management in Production and Services

Volume 11 • Issue 4 • 2019

Frequency

ECONOMICS AND MANAGEMENT
is published quarterly since 1998

As of the beginning of 2017 the journal
is published under a new name:
ENGINEERING MANAGEMENT
IN PRODUCTION AND SERVICES

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Publisher

Bialystok University of Technology
Wiejska 45A, 15-351 Bialystok, Poland

The International Society
for Manufacturing Service
and Management Engeneering (ISMSME)

Submission

Papers for submission should be prepared according to the *Authors Instructions* available at www.empas.pb.edu.pl

All papers should be submitted through the electronic submission system

Editor-in-Chief

Indexation

Journal is indexed in SCOPUS, EBSCO Business Source Ultimate (Complete), Norwegian Register for Scientific Journals, Series and Publishers, Index Copernicus, ERIH PLUS, Google Scholar, Central European Journal of Social Sciences and Humanities, Research Papers in Economics (RePEc), BazTech and BazEkon databases

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Scientific Secretary

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Technical Editors

Volume 11 • Issue 4 • 2019

Ministry of Science and Higher Education

Republic of Poland

Publishing of four issues of the “Engineering Management in Production and Services” journal in English – tasks financed in the framework of the contract no. 710/P-DUN/2019 by the Ministry of Science and Higher Education from the funds earmarked for the public understanding of science initiatives.

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ISMSME International Society for Manufacturing, Service and Management Engineering

received: 1 June 2019
accepted: 15 November 2019

pages: 7-22

Patterns of digitalisation in machinery-building industries: evidence from Russia

Yulia Turovets, Konstantin Vishnevskiy

ABSTRACT
Digitalisation in machinery-building is expected to enhance productivity and drive the digital transformation of other industries. The extant literature sparsely describes pathways of different sectors in digitalisation, considering the heterogeneous characteristics of firms and sectors. Emerging economies with important state participation represent a particular interest in this area of research. To this end, a multiple case study method was used to describe a set of determinants revealed from the literature on Russian technological development and innovation in manufacturing. Two different patterns were identified. The first one was typical for large leading firms with state participation, which have a global market presence and a substantial level of interoperability, currently turning into a service business model. Private firms that follow the second pattern focus on physical and digital infrastructure upgrading targeted at particular issues to secure connectivity across departments. The state participation does not have a decisive role in digitalisation decisions; however, it affects the participation of companies in national digital initiatives. This study is a preliminary analysis of the determinants associated with corporate digitalisation from the sectoral perspective. Since both national and corporate strategies are ongoing, it seems premature to make generalised conclusions. Instead, the paper provides useful insights for management and policy that refer to digital technology uptake by machinery-building industries.

KEY WORDS
digitalisation, machinery-building industries, Russia

DOI: 10.2478/emj-2019-0029

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Introduction

Being the core of manufacturing both in developed and developing countries, capital goods industries continue to play an important role in a country's economy. Machines and equipment affect a wide range of fields, contributing to efficiency gains and productivity, improvement in the quality of final goods and its technology intensity, dissemination of spill-over effects (Kwak and Kim, 2014; Rodrik, 1996; Ferris and Gawande, 1998; Min et al., 2018). Moreover, there is a particular interplay between ICT and the machinery equipment industry due to technology convergence that influences the whole value chain in different ways (Min et al., 2018).

Particularly, digital technologies impact on technological imperatives of the machine-building sector by enabling a close interaction between physical and virtual environments (OECD/IEA, 2017; OECD, 2017). Digitisation describes the process of converting analogue data into digital data sets (Rachinger et al., 2018). To pursue new opportunities, technological solutions based on such technologies provide digitalised data to create radically new products and services (Gobble, 2018). Such emerging sets of technologies change the relative efficiency of inputs, as well as the structure of production, and allow for productivity gains. The incorporation of new technologies is influenced by specific parameters, such as size, age, ownership structure or absorptive capacity (e.g. Tether, 2002; Aristei et al., 2016; Fagerberg and Srholec, 2016), but also depends on the expected market potential and the level of competition (Nelson and Winter, 1982; Aristei et al., 2016).

Although Russia is a leading technology producer in several fields, such as space equipment and energy machinery, its machine-building sector still suffers from outdated production methods (Szirmai, 2012). Recently, some papers have started addressing the digitalisation efforts and opportunities in Russia's economy (e.g. Lisovskii et al., 2018; Kudryavtseva et al., 2018). All these contributions stress the robust role of policies in Russia's economy in general as well as an enabler of digital strategies in particular. Two main issues should be considered while analysing the sector. The first refers to the heavy dependence of Russia's machine-building sector on foreign technologies as machines and equipment account for almost half (48.7%) of all Russia's import (Federal Customs Service, 2018). Secondly, the imposed sanctions on fuel and energy, as well as on the financial sector, led to a significant reduction in both investments and production volumes. The overhauled machine-building sector, on the other hand, would open export opportunities to European and Asian markets. This need is urgent as during the years 2014–2016, Russia's exports stagnated due to the decreasing global demand.

In the literature, machine-building sectors are recognised as a homogenous entity with a particular value of implicit knowledge and a business-centred model. A traditional chain of stakeholders encompasses three key groups: enablers (suppliers of digital solutions), machine-builders and customers that use equipment (Sommarberg and Mäkinen, 2019). Nevertheless, technological processes and customer relationships differ immensely.

The remainder of the paper is structured as follows. First, a brief literature review presents the digitalisation in manufacturing. The next part provides the assessment of the current technological level of the Russian machinery-building industries. The discussion investigates different determinants of digitalisation directions chosen by machinery-building companies. The summarised results propose several corporate recommendations and policy issues on possible ways to enhance industrial upgrading with digital technologies and to accelerate its adoption.

1. Literature review

The literature offers several strands with regard to digitalisation in manufacturing industries. The first mainly covers a micro-view and capacities to uptake emerging technologies. Often, articles diagnose a slow pursuit of business opportunities associated with digitalisation (Porter and Heppelmann, 2015; Lenka et al., 2017). However, the literature is still in its infancy as regards the new offerings and processes as a result of digitalisation and the redefinition of value creation between providers, customers, and other actors along the value chain (e.g. Rabetino et al., 2018; Parida et al., 2019). So far, resource-based views dominate the approach to competitive advantages derived from digitalisation (Lenka et al., 2017; Hasselblatt et al., 2018). In particular, the literature on the importance of platform thinking is instrumental in understanding emerging business models and the pursuit of strategic opportunities (Eloranta et al., 2016; Eloranta and Turunen, 2016; Cenamor et al., 2017).

Another strand of research scrutinises technologies that transform manufacturing and its implications, such as computer modelling, cyber-physical systems, the Internet of Things, cloud computing, big data, augmented reality, industrial automation and robotics and additive technologies (Esmaeilian et al., 2016; Ghobakhloo M., 2018; Kang et al., 2016; Strange and Zucchella, 2017; Tao et al., 2017; Szalavetz, 2018; Wang et al., 2017; Witkowski et al., 2017; Ślusarczyk et al. 2019; Alaeddin et al., 2018; Kohnová et al., 2019; Krykavskyy et al., 2019).

The technological and business opportunities offered by digitalisation require efforts that encourage most leading countries to launch government-led industry programmes to orchestrate the upscaling of their industrial base, e.g., China in 2025 (e.g. Chen, 2018), the smart manufacturing initiative of the USA (White House, 2016), and Germany's High Tech 2020 Strategy (e.g. Fuchs, 2018).

Digitalisation facilitates product development and gives an impetus for an overall transformation of outdated production processes in all industries. Numerous studies evidence ICT-sector products and services contribution to economic growth in developing countries, such as Singapore (Vu, 2013), South Korea (Hong et al., 2016; Hong, 2017), India (Mitra et al., 2016), Latin America (Hofman et al., 2016), as well as developed states like Germany (Strobel, 2016). However, economies, which lie below the world technology frontier, should choose a different route towards modern developments.

The first issue is the extensive dependence on foreign solutions. Embracing digital technologies may allow countries to roll out their solutions in prioritised technology fields, and, thus, alleviate often-disproportionate reliance on external technologies. The establishment of demand for own high-technology products is seen as the second greatest difficulty for latecomers (Kim and Lee, 2008). The solution demands an integrated approach to aligning stakeholders with the required financial support at most demanded directions. While government-led initiatives of leading technology producing countries are well researched, attempts of emerging economies to create technology base have received little attention.

Industrial competitiveness relies heavily on machinery and, more broadly, the competitiveness of investment goods as they contribute to the improvement of productivity, quality characteristics of the final goods produced with the help of machines, and higher technological opportunities overall (Kwak and Kim, 2015). In emerging countries, machinery industries are widely studied, to name a few, the latest research plastic injection moulding (Kwak et al., 2018) and military aircraft (Lee and Yoon, 2015) industries. Russian machinery sectors present an interesting case from the sectoral perspective and effects for the economy as a whole. This study closes the gap by presenting an analysis of determinants linked to the investments in digitalisation in machinery industries. It implies different sets of capability and, thus, demonstrates distinct trajectories of industrial upgrading (Lacasa et al., 2019; Lee and Malerba, 2017).

Considering a wide range of implications and prerequisites required to utilise the effects of digitalisation, the insights of the paper could be useful for policy issues. Such studies are still very limited with the exception of papers by Arens (2019) on the European steel industry and Gauthier et al. (2018) on policy level-changes for digitalisation adaptation. In most cases, such support strategies are discussed within the framework of Industry 4.0, a term that emerged from a policy discourse around the German initiative, which became a part of the new German High Tech Strategy 2025 introduced in 2018 (Bundesregierung, 2018; Luz Martín-Peña et al., 2018).

For traditional industries in developing and developed countries, digital technologies highly contribute to the overall economic growth (Stiroh, 2002). It provides a boost to productivity, which went down due to a decrease in growth rates of the total factor productivity (TFP) (Voskoboynikov, 2017). On average, the effects generated by digitalisation on productivity are higher for manufacturing that is linked to the automation of large part of routine operations (Akerman et al., 2013; Dhyne et al., 2018). Not by chance, national governments are developing digital strategies for production industries. This trend, though, is not new: ICT and technology upgrading were a key milestone for recovering after the financial and economic crisis in 2008. For example, the U.S. government launched the "Manufacturing USA" (formerly known as the National Network for Manufacturing Innovation), while catapult centres were initiated in the United Kingdom, and South Korea started the programme "Manufacturing Industry Innovation 3.0" and a network of 17 Creative Economy and Innovation Centres (ITIF, 2017). Emerging technologies facilitate costs reduction and production losses, enhance labour productivity, etc.

In summary, the study identifies factors of digitalisation pathways in the machine-building industry, with a particular focus on both private firms and companies with state participation.

2. Technological upgrading in the national digital agenda: the Russian perspective

Russia's development is in line with world trends, though it is facing the problem of productivity fall hindered by the need to bridge the technological gap (Voskoboynikov, 2017). Over the last decades, the latter has become a keynote. Since 2010, the Russian innovation and industrial policy has been converged with strategic goals and national technology priorities. This is not limited to the R&D increase but also the efforts targeted at the improvement of the investment climate and the development of new high-tech sectors (Simachev et al., 2014).

The first systemic effort of technology upgrading based on emerging digital technologies was introduced in the National Technology Initiative (NTI) in 2016. Several multi-lateral long-standing public-private partnerships were established in priority markets: AutoNet, AeroNet, EnergiNet, FinNet, FoodNet, HealthNet, MariNet, NeuroNet, SafeNet and TechNet. This was a cutting-edge direction for all industries that should bridge the gap in commercialisation and create the required legislative, organisational and business environments (NTI, 2018). By providing venture capital, the NTI also boosts small firms that develop technological entrepreneurship. However, NTI centres do not have sufficient shared facilities and equipment, which participants could use for the development and testing of new goods and services. However, the initiative is unavailable to all participants as it only covers a limited number of organisations in particular fields that concentrate main activities and resources within the framework of the NTI (Dezhina, 2018). There is a lack of mechanisms that ensure cooperation and, hence, incentives to build close innovative ties between participants.

The national programme (project) "Digital economy of the Russian Federation" is a recent and most comprehensive initiative. Started in 2017, it integrates a range of different projects and measures to create digital solutions and platforms, based mainly on domestically developed technologies and promote its further adoption in industries and public services, including health, education, industry, agriculture, construction, urban economy, transport and energy infrastructure, and financial services (Russian Government, 2019). In terms of innovation policy, the programme bridges digital solutions development with its consumptions by other sectors, which is anticipated to facilitate digital transformation and foster long-run economic growth.

The framework of the initiative specifies main directions to implement digital solutions by strengthening human resources for the digital economy, information infrastructure, information security, digital technologies, normative regulation of the digital environment, and digital public administration. The aforementioned elements and seven main technology blocks (neurotechnologies and artificial intelligence, distributed ledger technologies or blockchain, quantum technologies, new manufacturing technologies, robotics and sensors, wireless technologies, and augmented and virtual reality) stand for three main priority fields: 1) markets and sectors; 2) platforms and technologies; 3) environment (Russian Government, 2019). Such initiatives are mostly synchronised with the more recent NTI measures and substantially enlarge the previous agenda.

However, the digitalisation strategy for manufacturing is still nascent for the policy frame, compared with other countries like China, Japan, Germany, the USA, the UK, South Korea that have launched special industrial programmes starting with 2010. This has particular implications on the level of a company and the export competitiveness of manufacturers. According to representatives of companies, the lack of sufficient budget is the first obstacle in the digitalisation journey of Russian manufacturing companies (ISSEK NRU HSE, 2019a).

In summary, the initiatives of the Russian government aim to consolidate efforts by industry actors and knowledge producers and to provide financial support. Such an approach is in line with the strategic policy and has particular implications on the level of companies.

3. Current technological level of the Russian machine-building industries

In the scope of the current research, we consider machine-building industries broadly, including automobile, agriculture machinery, aircraft, heavy mechanical engineering, machine tool, power engineering, shipbuilding and transport machine-building industries. In the latest decade, the sectoral performance varied greatly. Most segments demonstrated growth after a decline of 2014–2015, which was triggered by sanctions and stagnant global demand, which mirrored in the Russian foreign trade. After the falling export volumes and a drastic drop in 2014, the trend reverted in 2017, and further prospects remain positive (Federal Customs Service, 2018). However, most Russian export is connected to niche high-tech goods with export volumes several times lower compared to those of the import.

Three main factors describe the technological level of machinery industries: 1) high dependence on foreign technologies, components and final machinery goods; 2) low innovative capacity of companies; and 3) insufficient investments in ICT and digital technologies.

3.1. High dependence on foreign technologies

Machines and equipment are the top imported goods in Russia. Despite a significant drop in 2015, the purchase of foreign equipment keeps rising (from a moderate 5% in 2016 to 28.2% in 2017), and now, accounts for almost half of all Russian imports (48.7%) (Federal Customs Service, 2018). Although Russian products in general and in machine-building in particular are improving in terms of their quality, Russian customers have a strong preference for imported products. Major efforts for reducing import dependence are limited to the localisation of foreign parts, components or a final product. This is the case of the automotive industry. Its upgrading is based on a set of measures intended to stimulate foreign investments by means of industrial assembly plants and an increase of duties on second-hand cars (Kuznetsov and Simachev, 2015).

3.2. Low innovation capacity of Russian firms

This preference of foreign products, both physical and digital, stems from the lack of competence in certain fields as well as missing product certification, and, on the other hand, from insufficient R&D activities (Dezhina, 2017; Kuzminov et al., 2018). Special software, such as PLM and MES systems, is delivered by such world leaders. To obtain a high level of automation, companies seek opportunities to ensure a modern physical infrastructure, such as machine tools, machining centres, robotics, etc. As an important part of the digitalisation strategy, companies invest heavily in capital assets through partnerships with foreign industrial robotics producers. Several reasons explain the extensive dependence on foreign technologies. The large part of Russian manufacturing companies faces a high level of special software and the adoption of relevant systems. At the same time, a piecewise digitalisation covers only a part of processes, which hinders efficient internal operation and cooperation with other participants (Dezhina et al., 2015).

Companies find it easier and faster to buy complete solutions abroad than to develop the domestically or internally, which results in low R&D involvement (Dezhina, 2017). The insufficient demand and the lack of technological competences result in low innovation capacity, which is typical for latecomer sectors (Kim and Lee, 2003). In this regard, a primary policy task is to enhance the motivation of companies to invest in new digital solutions for production. A set of policy measures should be broader and create an appropriate environment, where technological upgrading becomes an essential condition of the market success of the company.

An aggregate level of innovation activity, which also encompasses organisation and marketing innovations, amounts to 8.4%, while in Germany, this indicator is 67%. Such low level is a result of a small number of organisations that develop technological innovations (7.3%) in comparison with developed countries like Germany (52.6%), the UK (40.9%), South Korea (34.6%), China (26.9%) and the U.S. (12.8%) (NRU HSE, 2018b). At the same time, the distribution of financial support from the state in Russia almost coincides with the level of Germany, 21.8% and 21% respectively. This indicates a low efficiency of resources that do not lead to market introduction of new technologies and its further usage.

3.3. Insufficient investments in ICT and digital technologies

Another obstacle to digitalisation is low investment in new technologies. The proportion of spending on digital technologies makes up only 2.2% of the GDP in comparison with 5% in the US, 3.9% in Western Europe and 3.6% in Brazil (Digital McKinsey, 2017). Investment in innovative activities remained stable from 2006 onwards but did not show any signs of improvement (Balagurova et al., 2017). This statement is confirmed by the business. According to the survey of large and medium companies, 2/3 of enterprises estimated investments in digital technologies as low (ISSEK NRU HSE, 2018a).

Nevertheless, a slow digitalisation path is not exceptionally a Russian trend. In spite of high expected economic implications, transformation in European countries is also deploying a moderate path (European Union, 2018). According to the annual monitoring of German Federal Ministry for Economic Affairs and Energy, almost half of respondent enterprises pointed out the absence of necessity of digitalisation projects in 2016. In 2017, the figure changed and accounted for 29% (BMWi, 2018). This was possible partly due to federal policy and relevant initiatives.

Another key trend is a substantial gap between large leading companies and SMEs in the pace and scope of digital adoption. This depends on different requirements in digital technologies and its application field in small firms. As an example, cloud computing is more demanded by small and medium firms, since the solution allows reducing the costs for maintenance of physical parts of the information infrastructure and ensures access to data. Large companies often need solutions that integrate different functional fields into a single system, like Enterprise Resource Planning (ERP), MES, etc. (Gal et al., 2019).

The modernisation agenda is unwrapping on the background of the systemic challenges in the field of science and technology. Still, previous research showed systematic shortfalls in comparison to more developed countries (Gstraunthaler and Proskuryakova, 2012). Several research papers into Russia's national innovation system and notoriously low levels of investment activity revealed the inadequate collaboration between actors within the innovation chain as the main deficiency (e.g. Thurner and Zaichenko, 2016; Vishnevskiy et al., 2019).

4. Current level of Russian manufacturing digitalisation

The overall index of business digitalisation (28) of Russia lags behind most OECD countries, including the leader Finland (50) or Korea (45) as well as Turkey (33) (NRU HSE, 2019b). Companies show misbalance between the use of traditional and new digital solutions: together with wide dissemination of traditional technologies, such as access to broadband Internet, only 23% of firms use cloud technologies. In Finland, this indicator reached 65.3% in 2018. The indicators reflected the use of ERP-systems, which was even lower: 19% of Russian organisations in comparison with 54% in Belgium. In manufacturing, this indicator was higher (27%); however, only 1/3 of enterprises used CRM, ERP, SCM systems (NRU HSE, 2019b). The business survey also confirmed the results mentioned above: according to representatives of companies, every third firm was not prepared for the digital transformation (ISSEK NRU HSE, 2019a).

Official statistics evidence an extremely low rate of domestic development in ICT-related advanced manufacturing technologies (AMT) and a much higher demand for it: created technological solutions roughly account for only 1% of the number of technologies used by countries (NRU HSE, 2019). The largest part of developed solutions is concentrated in computer-aided design, engineering and consulting services. This type of technologies as well as more traditional, simple well-established solutions are also highly demanded by companies. More complex and advanced technologies are still hardly used by companies, including CAM, automatically controlled vehicles, complex robots, systems based on artificial intelligence. Modest innovation capacity and insufficient domestic demand result in a low market share of Russian machine producers. In the near future, they will face even stronger competition. Consequently, low output numbers do not allow for optimising production costs, technology upgrading and innovation activities.

An issue that could contribute to digital upgrading of manufacturing is the fact that Russia worked intensively on building its domestic engineering software platforms (Gershman and Thurner, 2018). These platforms have now reached technological maturity and offer an alternative to the country's dependence on imported technologies. Although software development still depends mainly on access to international technologies, Russia's IT sector is growing stronger. The sector makes a substantial contribution towards the country's digital development as its contribution to the GDP is forecast to reach 4.6% in 2030 when digitalisation in sectors may contribute to 30% of the GDP. In fact, the total factor productivity and capital contribution as major growth factors of the added value could reach up to 5% and, thus, become the greatest in machinery industries among all sectors (ISSEK NRU HSE, 2018c).

5. Methodology

This paper used the case study to verify the assumptions identified on the sectoral and firm-level and reveal patterns of digitalisation in machinery-building industries. A multiple case study was used to reveal different directions of digitalisation in industries with particular attention on state participation in company capital. The choice of method was driven by the intention to make a qualitative description of characteristics that might accelerate digital technology adoption, the transformation of business models and the enhancement of innovation capacities of the incumbent firms. The use of several cases allows identifying a set of practical issues based on heterogeneous data (Coreynen et al., 2017). The study provides a description and reasoning of the factors that interplay in terms of the digital transformation.

Empirical research contributes to theoretical issues of the digital transformation in machinery firms (Dul and Hak, 2008; Kwak et al., 2018). Based on research by Kwak et al. (2018), the study used purposive sampling for case selection that allowed testing the hypothesis and making relevant conclusions. Detailed examination of the cases (Rowley, 2002) was made to answer two main questions: 1) How is the digitalisation deployed in the machinery-building sector, and 2) Which are the factors that determine it. This enabled fruitful insights in the area of the adoption of emerging technology strategies and its implications for business (Vishnevskiy and Yaroslavtsev, 2017).

The reasons behind the choice of a small number of case study firms lie in the necessity of a thorough study of particular digitalisation issues that are currently hardly captured by official statistics. It was important to find cases that matched a set of requirements, namely: size and main activity, digitalisation strategy in a long-lasting period (ten years and more), diverse product portfolio. Another important issue was data availability and reliability. Thus, three segments in machine-building industries were selected — automotive, general machinery production and the transport machinery sector. By using purposive sampling, three firms were chosen. Each firm represented a type of the best practice, which demonstrated a relatively intense digital transformation and was recognised as one of the leading players in the corresponding machinery-building segment. Following the research by Coreynen et al. (2017), key characteristics of the companies were collected (Tab. 1) based on the data from the Bureau Van Dijk database. All companies were listed on the stock exchange.

The company sampling considered data availability and current realisation of the strategy linked to digitalisation. Desk research was used to collect the main sources, which comprised annual companies' official reports, industrial reports and journals, corporate journals, expert and analytical studies, and financial data from the Bureau Van Dijk database.

After the preliminary selection, the focus was directed to three large companies from the main machinery-building segments that represented the major part of the Russian machinery-building sector. Two of them were private and one — state-owned. All of them belonged to the categories "large" or "very large." The firm A was an important player in the automobile and engine market, being a part of one of the vertically integrated state corporations. The firm B produced energy equipment and occupied a strong position on the Russian and CIS markets. Finally, the third case was a private company, a part of a holding, that manufactured passenger cars of motive power. Thus, companies followed different patterns of digitalisation due to corporate and sectoral characteristics.

Based on the approach of Coreynen, Matthyssens and Van Bockhaven (2017), two interviews were conducted with representatives of each firm responsible on digitalisation and supported obtained data with information from official annual reports, brochures and presentations, expert discussions and other sources of open data.

With the aim to exert a comprehensive analysis, three cases were analysed according to the following framework: 1) digitalisation and innovation scope: strategy coverage (product and process transformations due to digital technologies), establishment of digital transformation units within a company, provenance of digital solutions used by a company, current projects related to digitalisation, R&D activities, cooperation with science and research organisations, participation in the National technology initiative (NTI) and other innovation projects; 2) policy scope: state participation in a company, participation in government digital initiatives and government support opportunities seized by a company.

6. Overview of company digitalisation

In this section, each case description is made, which unveils some ways of the firms' digitalisation strategy and gives an opportunity to examine, how

Tab. 1. Main characteristics of the firms

Firms	Ownership	Main activity according to the NACE Rev. 2 classification	Size	Export directions
Firm A	company with state participation	manufacture of motor vehicles	very large	CIS, South Asia, Middle East, Africa, Eastern Europe, Latin America
Firm B	private	manufacture of general-purpose machinery	large	CIS, Europe, South Asia and other
Firm C	private	manufacture of railway locomotives and rolling stock	large	Belarus, CIS

Source: (Bureau Van Dijk, 2019) and company web sites and annual reports.

sectoral issues are mirrored on the level of a particular firm.

6.1. Firm A

Company A stands out among the Russian machine-building companies that successfully developed a digitalisation strategy. It has a long history of efforts towards digitalisation, which began in the middle of 2000. The strategy was rolled out for several consecutive stages. The first was the most important, lasted ten years and focused on the development of digital models, improving designs and testing products on digital platforms. In the next stage, a digital production facility was created, which integrated the product lifecycle management (PLM), resource planning (ERP), production planning and production management systems (MES). During this period, robotics and automation were also introduced, including CNC machines and machining centres. During the current third stage, the company is moving to servitisation and digital services, introducing a system for ongoing monitoring, diagnosing and transportation of produced vehicles based on an automated control system. The central element of the system will be a compatible development of "digital twins" of all elements — products, processes, machines and equipment — which form an integral system of single digital production space (Production Management, 2017; Gershman et al., 2016).

To upgrade a physical infrastructure and increase the level of automation, the company cooperates with a global supplier. The automation concept is an important part of the company's development strategy, which involves the introduction of almost 1000 robots and robotic elements. Moreover, a smart factory project is planned based on solutions from Siemens.

In addition to in-house R&D facilities, the company cooperates with participants of the National technology initiative on such projects as system engineering, the standardisation of the production process, elements, etc. Also, contacts have been signed with scientists from a federal university, including a laboratory, a technology centre for production automation (Production Management, 2017a). The company is a significant participant of the NTI platform and is involved in the development of fully autonomous vehicles and related applications.

Considering the intense automation of the production workshops of the company, the rate of digitalisation seems to be rather high. This is confirmed by the fact that corporate strategy together with the digitalisation of production and supply chain, sales and services, also contains the transformation of management systems and corporate culture. The latter includes such initiatives as the acceleration of digital transformation projects. Furthermore, efforts are undertaken to internally develop talents in the field of digital technologies. Some projects have been designed for training in management skills as well as monitoring and estimation of the corporate culture transformation.

6.2. Firm B

As a private player in energy machine-building, the current priorities of the firm are related to information integration and design, which cover all elements of a vertically integrated structure. In the middle of 2000, the company heavily invested in the consolidation of process automation and management. At that time, a modern ERP-system was implemented, which allowed standardising major business processes. During the next stage, the goal was to consolidate all processes in functional areas of the company's decision-making units (DMU), which resulted in the creation of a unified information system where all subsidiaries were included. The company established a central department of information technologies with several divisions, including information systems, information infrastructure, CAx tools etc. Moreover, customised sensors developed within the company provide data based on telematics to determine possible malfunctions in operation for planning predictive repairs, etc. (NRU HSE, 2018a).

In its digitalisation strategy, the firm mainly relies on foreign information products. As an ERP-system and 3D-modelling, it opted for the product of the foreign supplier. Currently, it is expected to update the system based on integrated solutions, including large data, machine learning, predictive models, etc. again, with foreign solutions. A single information platform would help to reduce the time spent on the preparation of design and production, which, in turn, would allow performing more projects in a given period.

Together with digital, a substantial budget was allocated for upgrading and modernising machine tools park. Modern high-precision machines embedded with numerical program control (CNC) will be integrated with other production systems. Further steps of digitalisation involve the transformation of the entire organisational architecture, more flexible interaction among departments and testing in a virtual environment. Several dimensions are involved in the field of monitoring systems and digitalisation of a process, which encompasses different systems of equipment diagnostics. Overall, the digitalisation across departments is in progress.

6.3. Firm C

The digital transformation of the company started later compared with the other two cases. The current set of activities is larger and addresses all business and production processes that will be implemented in several stages. An active phase of digitalisation started only several years ago. However, there is no single strategy or an official document. Instead, it is a set of initiatives that enables the deployment of a digital factory. This includes information systems integration, as well as physical modernisation of capital assets. From the physical point of view, the transformation includes industrial robot installation, measures for its productive use as well as solutions for monitoring in real-time and a single system as a part of the deployment of the Internet of Things (Production Management, 2017b).

Some pilots are aimed at the adoption of traceability procedures for products. From the digital point of view, main projects comprise the introduction of a monitoring system for manufacturing equipment, 3D-modeling, and a digital twin. A large share of initiatives is aimed at the compatibility of different systems in the supply chain, including internal planning and control, traceability of goods and materials, interactive digital manuals for employees, etc. All systems and newly adopted solutions should be integrated into a comprehensive ecosystem backed by modern information infrastructure. In doing so, the company relies mostly on already existing and widely used technologies, for example, the MES system in shop factories in different productive domains. Importantly, this solution is internally developed and meets the specific needs of the company.

The firm B does not participate in national digitalisation initiatives. The innovation activity of the company is based not only on internal capacities but also includes the collaboration with research centres and academic organisations of the sector. This is driven mostly by long cooperation ties in the industry but does not expand on newly launch national initiatives.

7. Discussion and findings

This study examined three large firms that represent the best practices in each of the Russian machinery-building segments. Two of them were vertically integrated state-owned companies. Such players are likely to become pioneers in digitalisation and technological upgrading due to their role in the economy and their access to financial resources. These large corporations act as multipliers due to their role in the value chain and facilitate the formation of a capable technological architecture. The firms collect valuable experience, which can be transferred to other enterprises and market segments (Thurner and Proskuryakova, 2014). Such an approach builds on the identification of lead enterprises, which successfully incorporate digital technologies as key learning cases. Such a nuanced policy approach considers the different rates of change in diverse sectors, while the development of industry standards facilitates the integration of lower-level suppliers and SMEs (Blind and Mangelsdorf, 2013; De Vries et al., 2009; Turovets et al., 2019; Turovets and Vishnevskiy, 2019).

Nevertheless, large companies are not the single driver of transformation in machinery-building. In spite of non-favourable external conditions that have been affecting the Russian business in the past several years, there is a trend of successful medium-sized companies, which also operate in some machinery industries, such as instrument-making, electronics etc. A medium company is usually specified according to the annual income, which is from RUB 50 million and up to 10 billion. Such firms actively conduct in-house R&D, have strong market positions (usually, niche) and a portfolio of customers. Also, they have a stable growth of annual income (~15%) and do not extensively depend on state support (Dezhina and Etzkowitz, 2016). Since such companies are often involved in the export of high-value goods, technological upgrading and digitalisation become essential to keep competitiveness on a global scale.

A reverse trend is particular for small enterprises: state support appears an important source of technological upgrading. Currently, their role in the economy is modest, they are not fully included in value chains as suppliers for large companies. To enhance small technology businesses, the current agenda provides several directions, including grants, venture capital, etc. (Dezhina and Etzkowitz, 2016). The key factor for them is the availability of capital. More broadly, a contribution of small firms to digitalisation is restricted due to their current role in the economy.

By the middle of 2019, all three firms, as well as most Russian industrial companies (ISSEK NRU

HSE, 2019a), have started digitalisation initiatives. Most of them are still in their first stages and need substantial investments for further development. Often, there is no single document of digital transformation, and related projects are recorded in the firms' main strategy. Only a few of them have a separate department for digital transformation, e.g. the firm A. Generally, these functions are performed by the IT-department. An absence of such a document could be explained as a vision problem: many firms see digitalisation mainly as a source of technological upgrading of capital assets. Only a small number demonstrates a high level of digitalisation and aims for intangible resources, business process transformation, corporate culture development and servitisation. The Product as a Service (PaaS) model, however, becomes a central part of the firm, where value is created via related services, including predictive analytics and maintenance, monitoring of equipment, etc. (ITIF, 2018). This leads to an increase of intangible assets, such as investments in R&D, training and retraining of personnel, organisational innovations (Bresnahan et al., 2002; Pilat, 2004; van Ark et al., 2008; Bloom 2012; Corrado et al., 2014). In most cases, digitalisation is still at the transitional stage, which includes the integration of different systems (ERP, MES, PLM) into a single frame, its compatibility with each other. Unsurprisingly, firms invest in digital modelling and engineering and dedicate a large part of digitalisation projects to the issue. The main challenge is, thus, to secure a single digital environment among all subsidies and departments.

Three cases show different directions chosen by firms to reach digital transformation. The framework of the study encompasses a set of determinants that affect digitalisation strategies, namely, the digitalisation focus (physical or digital modernisation), investments in machinery and equipment, innovation activity, size of a company, role in a value chain, the current business model, cooperation with universities and scientific organisations, and the servitisation of the business model.

Based on the determinants, two main patterns of digitalisation of Russian machine-building companies may be distinguished (Tab. 2). The first pattern is typical for the firm A. Due to its size, it disposes more resources to perform in-house R&D and, particularly, digital solutions. In terms of state support, companies with state participation engage more in national digitalisation initiatives. Such players demonstrate a high level of current digitalisation that enables to focus on investments in intangibles, which includes software and intellectual property. Gradually, they transformed their business model and became service-oriented.

The second pattern pursued by firms B and C also occurs in firms regardless of their role in the value chain. They purchase digital solutions outside, partly provide their R&D, and still focus more on physical, technological upgrading issues. In doing so, they mostly rely on proper funds. Unsurprisingly, such cooperation with industrial research centres is tighter, which allows obtaining specific solutions, but its scope is still insufficient. Current activities should ensure interoperability and connectivity across departments.

Findings on the level of firms correlate with the results of the survey conducted by the HSE in 2018. According to the assessment of the industrial enterprises that participated in the survey, most of them are currently developing digital strategies that cover cutting-edge automation and integration of production and business processes into a single system (24% of respondents) (NRU HSE, 2019a).

Companies rely on government financial support, most of them use internal resources for technological upgrading. This article argues that state incentives for the modernisation of manufacturing process show a stronger demand for more complex projects that include both physical and digital parts, such as the instalment of new product lines for new products, components and parts. New incentives provided under the national program "Digital Economy" could accelerate a rate of adoption of digital technologies and overcome the fragmentation in supply chains, including SMEs as downward suppliers.

Together with internal R&D reinforcement, there is a substantial room for cooperation between companies and research institutions that helps to mitigate the dependence on foreign technologies. Firm A (with state participation) is conducting R&D more actively with scientific and research organisations. To this end, leading Russian companies in different sectors could generate a strong demand for R&D results from research and academic institutions bringing these innovations to the market, closing the gap in commercialisation and facilitating an upgrade in educational programmes. The lack of skills and digital literacy within companies is a hurdle for business. According to the survey, 20% of enterprises demonstrated slow digitalisation due to the lack of experience and competences in digital technologies (NRU HSE, 2019a). It is worth mentioning that we do not reveal particular features of digitalisation that are

Tab. 2. Determinants of manufacturing digitalisation of Russian machine-building companies

Determinants	Firm A	Firm B	Firm C
Type of company 1. Very large with state participation 2. Large private	**1** 2	1 **2**	1 **2**
Role in a value chain 1. Diversified group of companies 2. Specialised producer of parts and machinery	**1** 2	1 **2**	1 **2**
Sources of digital solutions 1. In-house development of digital solutions 2. Both alternatives 3. Acquisition outside	1 **2** 3	1 **2** 3	1 **2** 3
Main directions of the digitalisation strategy 1. Modernisation of physical and digital infrastructure (hardware) 2. Both alternatives 3. Servitisation model	1 2 **3**	**1** 2 3	**1** 2 3
Provenance of digital technologies 1. Adoption of domestic solutions 2. Both alternatives 3. Adoption of foreign technologies	1 **2** 3	1 2 **3**	1 **2** 3
Sources for investments in digital technologies 1. Government support initiatives 2. Both alternatives 3. Proper resources of the company	1 2 **3**	1 2 **3**	1 **2** 3
Participation in national digital initiatives and projects 1. Participate actively 2. Perform own research	**1** 2	1 **2**	1 **2**
Participation in standards development 1. Member of technical committee 2. Don't participate	**1** 2	1 **2**	1 **2**

induced by sector diversity, which is consistent with other studies, for example, the survey of the U.S. companies (ITIF, 2018).

Knowing a company's profile could assist policymakers in specifying measures that help companies via digitalisation to develop their business, i.e., maintain positions for global leaders and for local leaders, ensure foreign market entry, while for stable longstanding players, give an impetus to strengthen their position on the national and, in the future, in foreign markets.

Conclusions

The transformation with digital technologies as a driver of economic development is a recent phenomenon, and thus, efficiency assessment of corporate strategies is still limited. Research efforts, such as this one, address pathways in different economic settings. This paper closes a gap in the literature as most contributions either look at individual companies or touch upon specific industry approaches. It also contributes to the growing body of literature on technology upgrading in emerging economies with substantial state participation. This study neither aims to provide a generalised approach to machinery firm directions towards digitalisation nor offers policy conclusions. On the contrary, it presents some references and avenues for managers and decision-makers.

Based on three cases selected by purposive sampling, the research identified two different patterns of digitalisation in sectors of the machine-building industry. State participation in a company's ownership positively affects cooperation with research and academic institutions; however, it substantially impacts on the choice of digital solutions developed domestically or abroad. For the majority of Russian machinery firms, the current strategy focuses on the integration and compatibility of a different system of production and business process. Only a limited number of companies achieved a level of digitalisation comparable with global leaders and moved to a service business model. Companies insufficiently participate in the development of standards related to digital technologies. At the same time, standardisation becomes a key issue in the digitalisation discussion that ensures interoperability of elements and systems.

New approaches to policymaking play an important role in encouraging business digitalisation. Russia's policymakers started a series of initiatives to support businesses in the development of digital technologies, to reduce the economy's import dependency and to open new export opportunities for local producers. Previous analyses showed that Russia has systemic weaknesses in its innovation system in comparison with advanced economies. One of these drawbacks is the notoriously low investment into research and development by private corporations and the low level of links among actors. Consequently, the newly established state initiatives aim to consolidate efforts by industry actors and knowledge producers as well as to provide financial support.

The variety of sector digitalisation arising from different types of organisation, corporate and structural characteristics (Andrews et al., 2018; OECD, 2019) should be considered while developing policy tools. Current digital initiatives should facilitate the uptake of digital technologies as they offer a set of mechanisms. Existing measures are not fully exploited by firms; besides, newly introduced instruments should ensure efficiency and long-term implications. The recently introduced national programme "Digital Economy" is expected to overcome existing drawbacks and ensure inclusive opportunities for different participants — small, medium and large firms. The policies described in this paper focus on the close collaboration with domestic academic and scientific organisations, as well as on enhancing the cooperation with international technology providers, both hardware and software. The aim is to integrate different actors in the value chains as well as upgrade production infrastructure and research activities.

Future works could provide insights into how such firms move towards digitalisation and which limitations they meet on this way, namely, the measurement of digitalisation effects on different aspects (organisational, financial, technological, etc.) of corporate performance.

Acknowledgements

The article was prepared within the framework of the Basic Research Program at the National Research University Higher School of Economics (HSE) and supported within the framework of the subsidy by the Russian Academic Excellence Project '5-100'.

This article was prepared as a part of a research project on the topic "Analysis and modelling dynamics of science and technology development with the use of statistical indicators", performed by the HSE in 2019.

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Volume 11 • Issue 4 • 2019

Engineering Management in Production and Services

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 30 May 2019
accepted: 10 November 2019

pages: 23-33

Classification of forecasting methods in production engineering

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ABSTRACT

Business management is a continuous decision-making process. It is difficult to imagine a company that does not use forecasting techniques. Even small enterprises without relevant forecasting departments more or less consciously anticipate future events, forecasting the volume of production and setting directions for development. Today's production companies must quickly adapt to changing customer requirements, implementing structural and technological changes and delivering projects related to the production of new products. Under the dynamically changing conditions, the functioning and effective management of modern enterprises depend on future-oriented information. This increases the validity of forecasting. This article aimed to identify forecasting methods and areas of their use in production engineering. The publications on this subject were reviewed in the Scopus database, using the time frame from January 1970 to June 2018. An original classification of research subareas was created using VOS viewer software, and then, a bibliometric map was developed to visualise the results of the word coexistence analysis. The analysis of the co-occurrence and co-classification of words made it possible to indicate research subareas of forecasting in production engineering and related emerging research areas and issues.

KEY WORDS

forecasting, forecasting methods, production engineering, manufacturing company

DOI: 10.2478/emj-2019-0030

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Introduction

For manufacturing companies, forecasting is part of the decision system. It is a future-oriented activity based on data from the past. It makes it easier for managers and planners to make decisions. The right choice means that an enterprise generates profits, reduces the risk of errors and losses. Forecasting is one of the basic elements when making decisions in the area of production. As forecasting is one of the key elements during the decision-making process in production, it was decided to conduct a bibliometric analysis to assess the dynamics of interest in this subject, reflected by the number of publications in the analysed period. The review of the publications was made in the Scopus database. The database was chosen because of its size and availability. Prognostic methods and subareas of their use in production engineering were identified. In the next stage, the classification of research subareas was created using VOS viewer software, and then, a bibliometric map was developed to visualise the results of the word coexistence analysis.

The article aims to identify the areas of research analysed in the literature concerning forecasting in production engineering. This measure represents the first stage of the research process, aiming to identify research problems in the field and a solution, which would constitute a theoretical and practical contribution to the development of production forecasting model. All the considerations and research in the field of discussed issues are covered in the following four chapters. The first chapter presents the topics addressed by authors in the context of production forecasting. Next, the methodology used for bibliometric analysis is described. The third chapter presents the results of the conducted bibliometric analysis. The final part analyses the obtained results and presents the conclusions.

1. Literature review

According to the definition of a Polish-language dictionary, "method" is a way to scientifically examine things and phenomena, and a set of rules used to examine reality (Słownik Nowy Języka Polskiego, 2002). One of the frequently used definitions of "research method" was proposed by A. Kamiński: "A team of theoretically justified conceptual and instrumental measures that broadly cover the whole of the researcher's investigations, aimed at solving a specific scientific problem" (Kamiński, 1974, p. 65). The current collection of forecasting methods is incredibly rich. It contains methods derived from many scientific disciplines. Forecasting methods can be divided into the following categories (Korol, 2010; Nazarko, 2004; Cortez et al., 1995; Box and Jenkins, 1970):

- methods of analysis and forecasting of time series, in which data regarding the current development of the forecasted variable and information are used in relation to current and future factors affecting the course of its development. Data analysis allows determining the correctness of development of the forecasted variable. The choice of the right model is based on the decomposition of the time series, which makes it possible to isolate the existing components in the analysed series and determining their mutual relations;
- statistical methods, in which forecasting is based on past regularities, regardless of the reason for their formation;
- analogue methods, in which with the future value of the variable is estimated based on data with similar variables that are causally unrelated to the projected variable;
- methods of cause-and-effect prediction, in which model parameters are determined based on a sample containing time series, cross-sectional or time-cross-sectional variables occurring in the model;
- heuristic methods (expert), in which opinions from several to several dozen experts are based on their experience and intuition.

According to the above classification, several forecasting methods are available with some being less and others more universal. Therefore, the identification of prognostic methods and subareas of their use in production engineering was made. Based on the review of the literature, topics presented by the authors in the context of production forecasting was presented.

The production of oil and gas is the dominating area, in which production forecasting is used. Crude oil, referred to as "black gold", is crucial for the global economy as a raw material of the chemical industry, but primarily, as one of the most important energy resources (Ejdys et al., 2014). Among all the articles, the majority concerned this subject. An example of a publication that discusses the production forecasting of both these raw materials is the study by Clark, Lake and Patzek. The authors recommend using a logistic trend model in this type of forecast (Clark et al., 2011). This model belongs to the group of analytical methods, in which the estimation is calculated by calculating the value of the appropriate function for the future moment of time. This assumes the invariability of the model until the forecast is determined (Maciąg et al., 2013). In turn, Wickens and De Jonge presented the process of forecasting oil production using the IAM model (Integrated Asset Model), which is used in the oil industry. This model includes probabilistic forecasts of plant performance and production, enabling an analysis of decision risk for strategic and operational decisions (Wickens and Jonge, 2006). In their article, Zhang, Orangi, Bakshi, Da Sie and Prasanna described the design and implementation of a prototype set of tools that demonstrated the functionality of the IAM model thanks to the integrated production and forecasting process (Zhang et al., 2006). In most studies, SSN was used to forecast production. The artificial network is a collection of interconnected elements called neurons (Ejdys et al., 2015). To predict oil production, Zhou and Liu used the BPNN (backpropagation neural network). The reverse propagation algorithm consists of such a change in the weight of the input signals of each neuron in each layer so that the error for the next learning pairs is as small as possible (Guanwu et al., 2017). Model verification yielded satisfactory results because of the network training process, which resulted in predicted values that were very good for real values (Zhou and Liu, 2009). In turn, Zhao, Huang, Li, and Zhang expanded BPNN based on the genetic algorithm (GA-BPNN), which allowed to obtain lower MAPE results than using BP neural networks. The authors used GA-BPNN to predict water abstraction and gas production in the process of optimising the anaerobic treatment of wastewater fermentation (Zhao et al., 2018). In contrast, Yang, Lin, Gong and Zhou combined the classic BP model with the dynamic particle swarm method to accurately predict the production of methane from coal seams. They developed a novel model of the neural network (DPSO-NN), which found application and efficiency in engineering prediction (Yang et al., 2018). In one of their earlier articles, Meling, Morkeseth and Langeland used a stochastic and analytical model to predict gas production (Meling et al., 1988). Sagheer and Kotb dealt with the limitation of traditional prognostic methods in the machine learning process. They proposed an approach to deep learning, which allowed to eliminate the limitations associated with traditional methods of forecasting. The proposed approach was a long-term short-term memory (DLSTM) architecture, an extension to the traditional repetitive neural network. The genetic algorithm has been used to optimally configure the DLSTM architecture. For verification purposes, production data of two oil fields were given. The proposed DLSTM model had better results than traditional prognostic methods (Sagheer and Kotb, 2018). Aizenberg et al. presented multilayer NN with multivalent neurons capable of predicting oil production based on time series. This model is built based on a neural network with a complex structure with a derivative-free backpropagation algorithm (Aizenberg et al., 2016).

Another area covered in the production forecasting publications is the forecasting of energy production. For this purpose, the authors of the publication most often use artificial neural networks. For example, Xu, Chen, Tang, and Li addressed the problem of forecasting energy production for a generation system connected to the BIPV (Building Integrated Photovoltaic) network. The authors stated that artificial intelligence methods, such as artificial neural networks, were the developmental direction for the modelling of energy production forecasting used for generation systems connected to the BIPV network (Xu et al., 2012). Theocharides, Makrides, Georghiou and Kyprianou used artificial neural networks (ANN), regression of the support vector (SVR) and regression tree (RT) to predict photovoltaic (PV) production with different parameters and properties. Their main goal was to assess the performance of various machine learning models to determine the output power of PV systems. The output prediction efficiency of the models was tested on actual PV production data and evaluated based on absolute percentage error (MAPE), and normalised core mean square error (nRMSE). A comparative analysis showed that artificial neural networks were the best because of the smallest errors (Theocharides et al., 2018). To predict PV production, Gligor, Dumitru and Grif used artificial intelligence, which predicted and managed the production of a PV power plant located in the central part of Romania. Its main task was to develop a solution that forecasted electricity production in real-time based on historical and current solar radiation data (Gligor et al., 2018). Wasilewski proposed the ARIMAX model for short-term forecasting of electricity production (Wasilewski, 2014). It is an extension of the ARIMA model that includes additional exogenous variables "X" in the model (Chunyan and Jun, 2009). Jones applied a combination of the ARIMAX model and hypothesis testing to forecasting in the power sector. Hypothesis testing refers to formal procedures used by statisticians to accept or reject the statistical hypothesis (Jones, 2004).

The next area that uses production forecasting is the production in industrial agriculture. For example, Rahmat et al. used an adaptive neuro-fuzzy inference system (ANFIS) to predict the production of rubber milk (Rahmat et al., 2018). Qader, Dash and Atkinson attempted to predict the production volume of wheat and barley in arid and semi-arid regions, which were the main cereal crops in many parts of the world and their production influenced local food safety. The authors used remotely sensed primary productivity and crop phenology (Qader et al., 2018). In turn, Mustafa and Jbara used the ARIMA model to forecast wheat production (Mustafa and Jbara, 2018). Also, Farhan, Hassnain, Irum and Abdul used the ARIMA model for milk production in Pakistan (Farhan et al., 2011). Alam, Sinha et al. used the hybrid ARIMA model with the SSN approach to predict rice production. This hybrid model significantly reduced the MAPE compared with ARIMA alone (Alam et al., 2018). De Oliveira, Mendes-Moreira and Ferreira (2018) used four methods to forecast grape production. The selected methods were multivariate linear regression, regression trees, lasso and random forest. The selected methods were verified using the mean squared error and the coefficient of variation (de Oliveira et al., 2018).

Another identified field that uses production forecasts is the automotive industry. Lin, Wong and Ho indicated that the process of the production chain in the automotive industry is directly dependent on the accuracy of its production forecasting model (e.g., the level of safety stocks, lack of inventory or timeliness). This article presents the Chinese automotive industry as a case study. The authors present an integrated model based on the grey neural network, which is a combination of the GM model (grey model) and a neural network. The GM model can be used for prediction in non-linear time series. The model is used especially in situations where the number of observations is insufficient (Chunyan et al., 2016). Experimental results show that integrated models have higher prediction accuracy than a single GM model (grey model) and neural network (Lin et al., 2015). One of the branches of the automotive industry is the production of electric cars. An article by Wang and Li was found in the database regarding the use of a logistics trend model to forecast the production of this type of vehicles. The conclusions drawn from the forecast indicate that global production of electric cars will enter the phase of rapid development (Wang and Li, 2011). In turn, Ngadono and Ikatrinasari used the ARIMA model to forecast the production capacity to create a PVB film needed in the process of laminating car glass (Ngadono and Ikatrinasari, 2018). In contrast, Subramaniyan, Skoogh, Salomonsson, Bangalore and Bokrantz developed an algorithm for predicting bottlenecks on production lines in the automotive industry. They combined the ARIMA methodology with a real-data-based technique, making it easier for engineers to manage bottlenecks and achieve higher bandwidth (Subramaniyan et al., 2018). Lai, Shui and Ni used a Two-Layer Long Short-Term Memory (LSTM) to predict bottlenecks on the chassis assembly line. This neural network-based approach takes advantage of the historical high dimensional factory floor data to make real-time predictions considering future production planning inputs (Lai et al., 2018). To predict production in the Chinese automotive industry, Lin, Wong and Ho presented three kinds of combined models based on a grey neural network, namely, a parallel grey neural network, series grey neural network, and inlaid grey neural network compared the single model GM and neural network. The experimental results demonstrated that the combined models had higher forecasting accuracy than the single model (Lin et al., 2014).

Other publications identified in the database did not concern production forecasting directly. They mainly concerned demand forecasting (Stanton et al., 1969; Raine, 1971; Tong and Sun, 2010; Li and Lim, 2018), further sales (Yelland, 2011) and forecasting in the supply chain (Liang, 2016).

2. Research methods

To identify methods and areas of forecasting in production engineering, and due to the review nature of the publication, the bibliometric analysis method was used as a research method. A review of the publication was made in the Scopus database. The selection of the database was made due to its size and availability. The first formulation, based on which the database was searched, was forecasting in production engineering used in article titles, abstracts and keywords. As a result of the search, only one publication was found, entitled "Technological forecasting and production engineering research" from 1970. This paper describes the qualitative and quantitative methods of forecasting technology and presents the results of forecasts using the Delphi method (Merchant, 2018). Because no satisfactory results were derived from the exploration of publications using the above combination of words, the phrase was modified. The aim was to remain as close as possible to the original wording and stay related to the studied subject. The most accurate phrase to explore the database was production forecasting used in article titles, abstracts and keywords. The time frame of the analysed period covered the years from January 1970 to June 2018.

In the second part of the research, the coexistence of words was assessed as well as their co-classification in publications. The method used to analyse the coexistence of words was based on counting the sequence of words appearing in the text. Using the VOS viewer software, a bibliometric map was developed, which is a visualisation of the results of the word coexistence analysis (Halicka, 2017; Gudanowska, 2017; Siderska & Jadaa, 2018; Szpilko, 2017, Winkowska et al., 2019). The size of the circles reflects the number of specific words, while the distance between the circles depends on the number of coexistences (Halicka, 2016). This method enabled the creation of the classification of forecasting methods in production engineering.

3. Research results

Exploration of Scopus database resulted in 726 studies found registered in the database, of which the largest part (Fig. 1) was composed of conference proceedings, the number of which was 403 (55.5%), articles — 278 (38.3%), and conference reviews — 25 (3.4%).

Most publications were created in the United States (215 articles), China (69 articles), Canada (57 articles) and Great Britain (35 articles). In the next step, it was decided to analyse the interest in the subject matter over the years. The time frame of the analysed period covered the years from January 1970 to June 2018, because the oldest publication came from 1970. The number of studies published in individual years is shown in Fig. 2.

For many years of the analysed period, the interest in the subject of forecasting production was moderate and remained rather low. It was only from around 2010 that an upward trend could be observed in the context of the number of studies related to the studied subject. A particularly dynamic increase in the number of publications started in 2012. In the years 2014–2017, the number of articles remained rather steady:

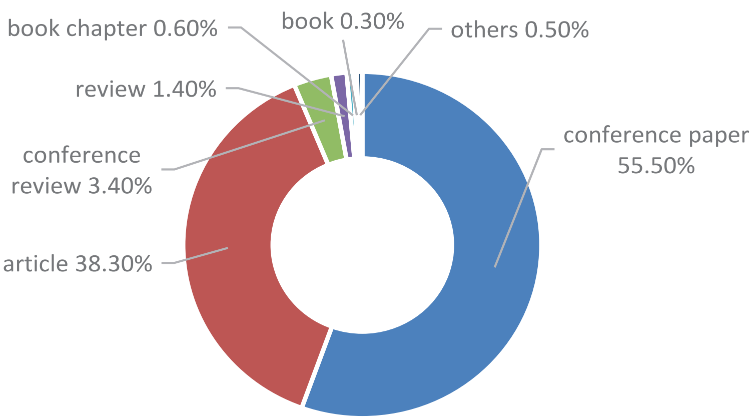

Fig. 1. Results of searching the Scopus database — the document type criterion

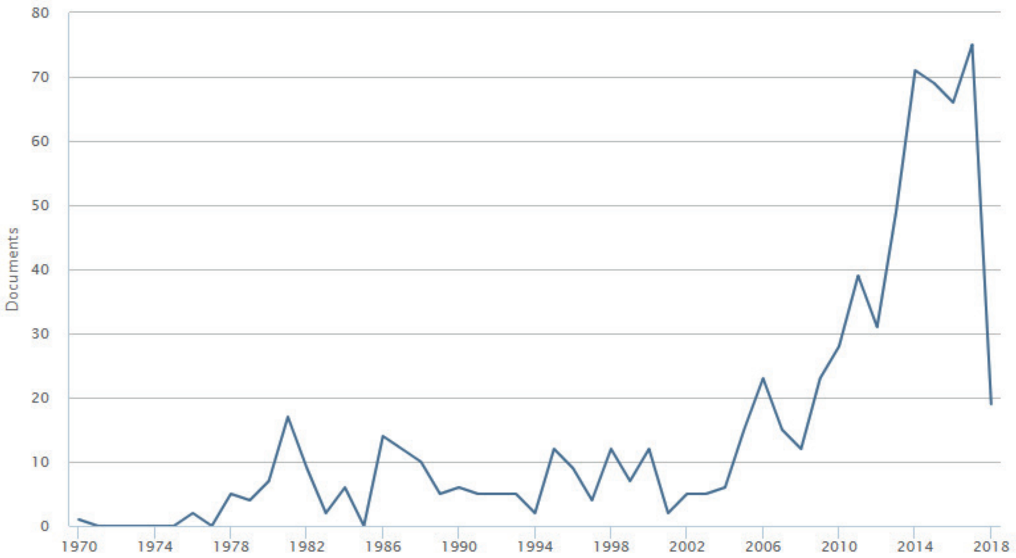

Fig. 2. Number of publications in the field of production forecasting in the Scopus database indexed January 1970 to June 2018

- 2014 — 71 publications;
- 2015 — 69 publications;
- 2016 — 66 publications;
- 2017 — 75 publications.

However, this is still not much, so it may mean that production forecasting is a topic that has not been thoroughly explored yet and is of interest both to researchers, researchers and production managers. Cooperation between enterprises and scientific institutions are the main actions required for successful development (Radziszewski et al., 2016, p. 168).

In the next stage, the classification of research subareas was created using the VOS viewer software, and then, a bibliometric map was developed, which is a visualisation of the results of the word coexistence analysis. The results of the analysis of articles from the Scopus database are presented in Fig. 3.

The word coexistence analysis made it possible to distinguish three clusters — A, B and C. Each cluster represents a specific group of methods used in forecasting in production engineering. The following subgroups have been identified:

- Cluster A — classical methods;
- Cluster B — artificial intelligence methods;
- Cluster C — hybrid methods.

4. Discussion of the results

The first cluster — A — includes forecasting methods in production engineering defined by the author as classical. This group includes forecasting methods that can be classified as the oldest methods used in production engineering, which are strongly represented in the literature. Many studies describe these methods. It is a group that covers numerical methods, statistical (ANOVA, NARX model, comprehensive statistical analysis, statistical method), analytical (analytical technique, analytical production prediction, linearization, nonlinear function), qualitative models, probabilistic methods (probabilistic forecasting approach, probabilistic prediction), time series methods (time series analysis), trend analysis methods, fuzzy time series, regression and autoregression models (mean kriging, non linear regression, ARIMA, ARMA, autoregressive model, autoregression), simulation methods (Monte Carlo simulation, Monte Carlo analysis). It is the most copious of the three groups of methods identified during the study. Currently, many researchers aiming to determine the most accurate forecast of production,

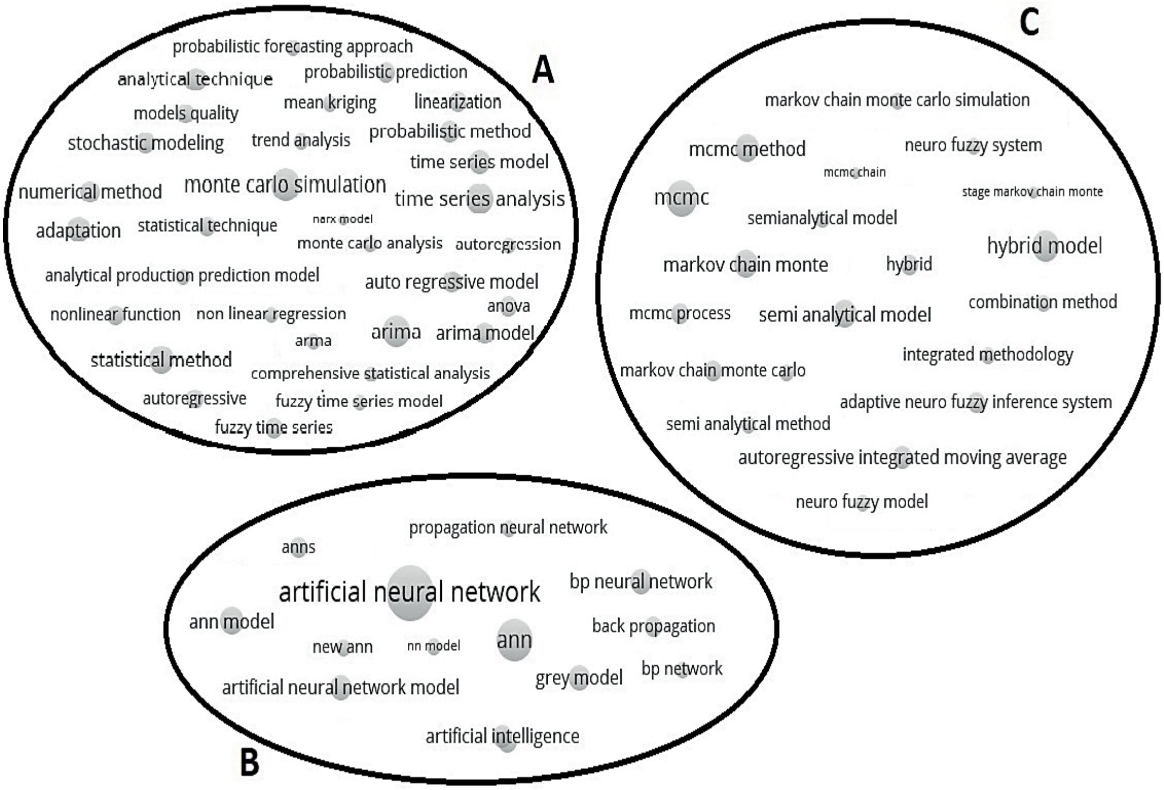

Fig. 3. Classification of forecasting methods in production engineering

depart from the use of only one of these methods, favouring a combination. More specifically, the process of combining methods was described in cluster C.

Cluster B contained artificial intelligence methods. Artificial intelligence is one of the top themes these days. It is used in many areas, including forecasting production. Often, artificial intelligence methods allow obtaining more accurate predictions and smaller errors in production forecasts. The literature analysis made it possible to indicate artificial intelligence methods most often used in forecasting in production engineering. Among them were the propagation neural network, the backpropagation neural network and the grey model.

The last cluster — C — covered hybrid methods, i.e., sets of methods that were a mixture of classical methods and artificial neural networks, as well as ANN–ANN combinations. This can be described as an integrated approach. Based on the literature analysis, such hybrids could allow obtaining the best results in forecasting production because such synergies enable to use the strengths of the selected methods. Depending on the type and specifics of the manufacturing industry and the nature of the data, the appropriate prognostic method should be chosen. This indicates a scientific gap that requires further research. The literature has no clear indication related to the effect made by matching methods, principles used to choose methods and factors on the choice of a forecasting method in production engineering.

The co-occurrence analysis and the co-classification of words made it possible to identify three clusters that constituted research subareas in the context of forecasting in production engineering. Tab. 1 indicates the research subareas of forecasting in production engineering and related emerging research directions and issues.

Based on the problems solved using individual groups of methods, conclusions can be drawn about their specificity. Classic forecasting methods are used for rather simple issues. On the other hand, methods from clusters B and C are advanced, intelligent methods that not only allow obtaining information based on available data but also allow modelling production processes. According to the author, hybrid methods — the combination of classic methods and artificial intelligence methods — allow creating a forecasting model that uses the advantages of both approaches, which simultaneously increases the accuracy and quality of the forecast and extends the possibilities of using the model.

Conclusions

Forecasting production is one of the key stages ensuring the correct course of business. Based on information from the forecast, managers make key decisions. Determining the right forecast requires the correct use of production data. Forecasts allow companies to maximise profits, reduce the risk of improper decisions, errors and losses. The publication aimed to review the literature in the field of production forecasting. It was carried out in the Scopus database, and the time frame of the analysed period covered 48 years (1970–2018). In the analysed period, the initial interest in the subject was low. Increasingly

Tab. 1. Research subareas of forecasting in production engineering

Cluster	Group of methods	Research subareas	Main research issues
A	classical methods	the possibility of obtaining information that objectively reflects the economic situation of an enterprise	• forecasting of the prime cost of production based on the calculation of the complex influence of production factors on this indicator (Yureneva et al., 2020; Kuladzhi et al., 2017; Trubaev and Tarasyuk, 2017; Mustavaeva, 2007); • prediction of production volume (Tkachev et al., 2018; Mustavaeva, 2007; Dupré et al., 2020; Artun et al., 2014); • operational cost management (Barinova and Shikhova, 2016, Yureneva and Barinova, 2016; Shim et al., 2009)
B	artificial intelligence methods	adaptive modelling of production processes	• improve management processes (Alva et al. 2020; Tariq et al., 2019; Sarma et al., 2018; Tariq, 2018; Jain et al., 2018); • predict cycle times of a common operation (Onaran and Yanik, 2020; Gyulai et al., 2020; Okubo et al., 2020; Wang and Jiang, 2019; Susanto et al., 2012; Eraslan, 2009)
C	hybrid methods	predictive modelling and probabilistic forecasting	• planning of production volume (Elgharbi et al., 2020; Li et al., 2018; Wu et al., 2017)

more publications were published every year. Until 2010, few studies were prepared. Later, the interest grew steadily, and then stabilised since 2014 and remained as such until now. In the last stage of the bibliometric analysis focused on the co-occurrence of words and their co-classification in publications. The word coexistence analysis was made using the VOS viewer software. A bibliometric map was prepared, and on this basis, the classification of forecasting methods in production engineering was made. Three groups of methods were distinguished — classical methods, artificial intelligence methods and hybrid methods, i.e., a mixture of classical methods and artificial neural networks as well as ANN-ANN combinations. In the age of the 4.0 industry, the importance of prognostic knowledge and knowledge of the use of artificial intelligence methods increases. Employers expect prognostic skills from managers in managerial positions. It is important to understand the future, and this can only be done by studying this field of science. As the manufacturing industry is varied, has numerous characteristics and specialises in different fields, there is no universal forecasting method that could be used by all manufacturing companies. As a result, various methods are combined, and integrated resource modelling is built to best match production data and, thus, result in more accurate forecasts. Aiming to find the criteria for the selection of combined methods and factors influencing their choice, research in this field of science should be continued.

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Volume 11 • Issue 4 • 2019

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 5 July 2019
accepted: 5 November 2019

pages: 34-42

Validating a destructive measurement system using Gauge R&R — a case study

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ABSTRACT
The research study aims to evaluate the precision of the measurement system using Gauge R&R. An experimental research design adopting a positivist empirical approach with deductive strategy was followed to assess the effectiveness of Crossed Gauge R&R technique for validating a measurement system using destructive testing. Crossed Gauge R&R technique in Minitab was found to be highly effective in quantifying different components of measurement variation relative to process variation. Clue generation from the Crossed Gauge R&R study combined with manufacturing and measurement process know-how helped in identifying and eliminating the root causes for measurement variation. Overall Crossed Gauge R&R proved successful in validating the burst strength test equipment. However, it should be noted that manufacturing and test equipment played an equally important part in developing and executing the gauge R&R study and accurately analysing the results. So, Crossed Gauge R&R should be used as an aid rather than the solution for measurement system validation.

KEY WORDS
Six Sigma, destructive testing, measurement system analysis, Gauge R&R, crossed Gauge R&R

DOI: 10.2478/emj-2019-0031

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Introduction

Metrology in quality management processes is much more advanced today than it was a few decades ago, thus placing a higher emphasis on empirical data (Messina, 1987; Miller and Freund, 1965). Organisations worldwide rely on sophisticated measurement equipment to collect this data for key characteristics of a product or process. However, these characteristics cannot be measured with perfect certainty. There are always errors when measurements are carried out, which means if a characteristic is measured again, it will result in a different value. In this context, Measurement Systems Analysis (a collection of statistical methods) is a popular technique for the analysis of measurement system capability (Automotive Industry Action Group [AIAG], 2002; Smith et al., 2007).

In particular, Gauge R&R is an industry-standard technique to evaluate measurement equipment for precision. However, achieving reproducible results is more challenging in the context of destructive testing as parts are destroyed during measurement and cannot be measured again. The current study aims to evaluate the existing Gauge R&R methods for quantifying measurement variation and defining validation criteria for measurement equipment that uses destructive testing. A number of applied research studies have been conducted in the area of Gage R&R for non-destructive testing (e.g. Barbosa et al., 2014; Peruchi et al., 2013; Liangxing et al., 2014; Hoffa and Laux, 2007); however, there seems to be a dearth of research into applications of Gauge R&R for destructive measurement system. An examination by Han and He (2007) used the Gauge R&R model to validate a rip-off force measurement system. Just one-off research in the last 20 years is too limited in scope to provide any useful insights, so the current study aimed to provide further cognisance into the applications of Gage R&R model for destructive testing. Further, a Crossed Gauge R&R technique, instead of Nested Gauge R&R, was applied for validating a burst strength test equipment (destructive test), which was a new measurement device using a plastic welded thermostatic cartridge sub-assembly used in mixer showers subjected to high-pressure water. Such a process has not been tested before.

This research study was conducted in a UK-based, global plumbing company, renowned for its bathroom products. The sub-assembly product in focus was an ultrasonically welded part and the key process output variable burst strength, which also served as a key performance indicator. Burst strength of an ultrasonic weld is measured by slowly increasing water pressure through the part until it fractures. Well documented validation criteria existed for most measurement equipment except for burst strength test equipment, as it involved destructive testing. The research study aimed to evaluate the precision of the measurement system using Gauge R&R. This article begins by presenting a literature review of the key findings in this area that provides further justification for the current study, followed by the research design and methodology section. Next, a section on research results provides detailed information and metrics on how the application of Gauge R&R technique performed in destructive testing. Application of the results from the current study will be compared to previous research findings in the discussion section, which will then lead to the conclusion and references at the end. Limitations of the current research and possible directions for future research will also be discussed in the conclusion section.

1. Literature review

Six Sigma is a popular quality improvement methodology that aims to significantly improve the quality of a manufacturing process and reduce costs by minimising process variation and reducing defects (Breyfogle and Meadows, 2001; Breyfogle et al., 2001, Sujová et al., 2019). In a manufacturing or assembly process, all its sub-processes are known to inherently possess a variation (Juran and Godfrey, 1999; Mckay and Steiner, 1997). Reduction of a process variation is contingent on an understanding of the relative contributions of various input variables on key performance indicators of the processes. Equally important is the ability to discriminate between process and measurement variations (Ishikawa, 1982; Juran, 1990; Persijn and Nuland, 1996).

Measurement System Analysis (MSA) attempts to quantify the measurement error relative to process tolerance and variation using statistical techniques (Mast and Trip, 2005). If measurement system variation is found to be high (>10%), then most efforts must be directed towards its moderation, prior to embarking upon achievement of a reduction in process variation. This hierarchy in prioritisation is evident in the Six Sigma methodology that emphasises the measurements' monitoring as a significant analysis activity during the Measure phase prior to data collection and Analyse phases (Pande et al., 2002).

Measurement system analysis (MSA) is defined as "a collection of instruments or gauges, standards, operations, methods, fixtures, software, personnel, environment, and assumptions used to quantify a unit of measure or the complete process used to obtain measurements" AIAG (2002, p. 5). Quantification of measurement error through close scrutiny of diverse variation sources, including the measurement system, the operators, and the parts is central to MSA. Variation in a measurement system consists of four distinct components: (i) bias which refers to the difference between the values of measurement and reference values, (ii) stability serves as a quantifiable indicator of fluctuations in bias over time, (iii) repeatability accounts for measurement variations caused due to inherent errors in the instrument, also referred to as precision, and (iv) reproducibility captures environmental fluctuations arising due to the unique setups and techniques of external sources, such as operators (Engel and De Vries, 1997; Smith et al., 2007). Appropriateness of the gauge for the intended application is best assessed using the repeatability and reproducibility components of a Gauge Repeatability & Reproducibility (GR&R) study (Burdick et al., 2005).

Abundant literature is available on the procedures and relevance of gauge reproducibility and repeatability studies (e.g., Burdick et al., 2003; Dolezal et al., 1998; Goffnet, 2004; Pan, 2004, 2006; Persijn and Nuland, 1996; Smith et al., 2007; Vardeman and Job, 1999). For example, Wesff (2012) published data on how a significant defect reduction in the measurement system, resulting in a massive saving of about $130,000 per year, was achieved by replacing continental automotive systems and reprogramming of the equipment's software language. Similarly, Bhakri and Belokar (2017) reported on the effectiveness of conducting a Gauge R&R study in achieving a reduction in measurement variation from 37.6% to 14.2%.

Repeatability measurement reiterates recurrent measurements of a part, thus mapping the internal, 'within operator', variability in gauge, resulting from the measurement system. Reproducibility, on the other hand, accounts for the environmental fluctuations, also known as 'between operator' variations, arising from gauge and external factors such as time (Smith et al., 2007; Pan, 2004). This is achieved by an assessment of variability sourced from manifold operators attempting recurrent measurements of a specific component (Pan, 2006; Tsai, 1989).

A combined estimate of both reproducibility and repeatability variations is referred to as Total Gauge R&R. In addition, total measurement system variation is the sum of the individual parts' variation and total Gauge R&R (AIAG, 2002; Pan, 2006). Assessing the suitability of the examined measurement systems using the Gauge R&R study was the primary goal of this paper.

2. Research methods

The overall aim of this research was to evaluate the effectiveness of Crossed Gauge RnR (ANNOVA) in quantifying measurement error for a destructive measurement system. The manufacturing and assembly process of a mixer shower cartridge that controls the outlet flow and temperature was selected. One of the key performance indicators for the product and process is the burst strength of the assembled cartridge. Burst strength of a cartridge is measured by slowly ramping up water pressure until it fails. Specific research objectives were to evaluate the utility of Crossed Gauge R&R technique in:

- Quantifying measurement variation coming from the burst strength test rig;
- Identifying the source of measurement variation in the burst strength test rig;
- Defining a validation procedure for measurement equipment that uses destructive testing.

The concerned manufacturing company, wherein the current study was conducted, had a high focus on quality systems that included MSA studies for all measurement equipment used in the laboratory or the shop floor. Currently, there was no qualification method for the burst strength test rig and, hence, the quality of the product could not be confirmed reliably. The burst strength test confirms the structural integrity of the product, and without a satisfactory measurement system, it could result in the bad product reaching customers and leading to safety and operational hazard.

Aiming to make a Gauge R&R study viable, during a destructive measurement process, homogeneity of batches and the component parts is essential (Montgomery, 2001, 2013). Homogeneity in batches is indicated by a collection of similar measurement parts/specimens that are likely to yield similar results. Inherent similarities in components enable repeated measurements of parts that may have been destroyed. An action-oriented, quantitative research methodology was used. Reliable statistical techniques are available for an effective calculation of repeatability and reproducibility of a destructive measurement process. Statistical software Minitab (2002) was used as a medium for conducting statistical analyses. Minitab possesses two inbuilt, standard methodologies for conducting Gauge RnR: Crossed and Nested Gauge R&R. For effective execution of analysis under a crossed design, batch sizes of homogeneous parts must be large enough so that each operator can measure at least two parts from each batch (Box et al., 1978). Example of a crossed experimental design is shown in (Fig. 1).

In a crossed experimental model, operator by batch interactions is mapped across numerous operators, owing to significantly large batch sizes. However, in the case of relatively small sizes of the homogeneous batches, wherein, multiple parts from a batch cannot be allocated to several operators, a nested or hierarchical model is more appropriate, as shown in (Fig. 2).

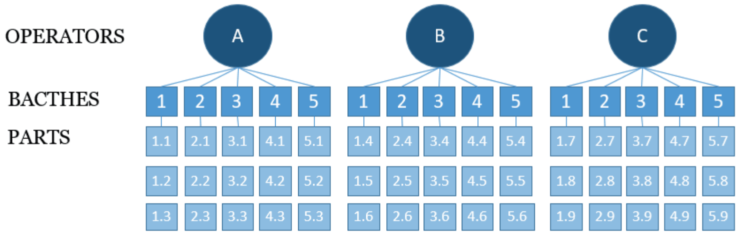

Fig. 1. Crossed experimental model

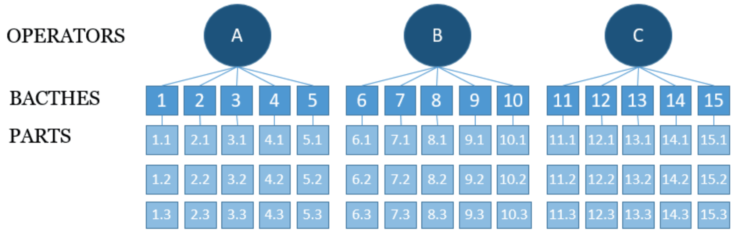

Fig. 2. Nested experimental model

Validation of burst strength measurement equipment was undertaken in the current research study. Burst strength of ultrasonic welded plastic components was measured using destructive testing. Batches were created with different burst strengths covering the operational range of the product. As multiple parts within batches can be manufactured and provided to randomly selected operators, a crossed Gauge RnR model was deemed suitable.

3. Research results

This section covers the key findings from the current study against key objectives, which are shown below:

- Quantifying measurement variation coming from the burst strength test rig;
- Identifying the source of measurement variation in the burst strength test rig;
- Defining a validation procedure for measurement equipment that uses destructive testing.

Further information on key results from each stage of the research is discussed below.

As already discussed, creating homogeneous batches with a reasonable sample size is critical to the success of Crossed Gauge R&R study. Further, these batches should cover the entire operational range of the product or measurement equipment. Key manufacturing process that defined the burst strength of the product was the ultrasonic welding of two plastic components. Even before MSA could start, the first step was to identify settings for key input variables to generate desired homogenous batches covering the range of burst strength measurements. A design of experiment (DoE) was conducted to characterise key input variables against the burst strength of the welded part. For example, (Fig. 3) shows the CNX diagram for DoE.

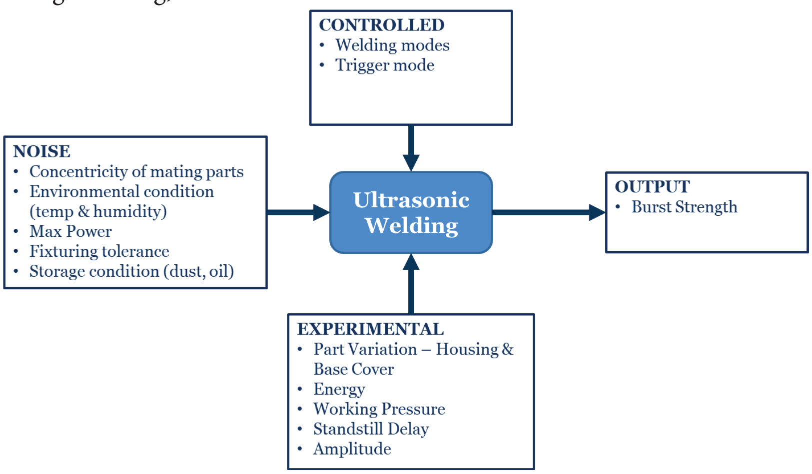

Fig. 3. CNX diagram for design of experiments

A 2-level 6-factor ½-fractional factorial design of experiments was conducted, and the results were analysed using the Minitab software. As an example, Fig. 4 shows all the statistically significant factors and interactions relative to their impact on the burst strength.

Summary of DoE analysis results from the Minitab software is presented in Tab. 1. A high R-sq value of 99.58% means that the regression model created for DoE explains 99.58% of the total variation seen in the process, which is extremely good. Factors or interaction with p-value < 0.05 have a statistically

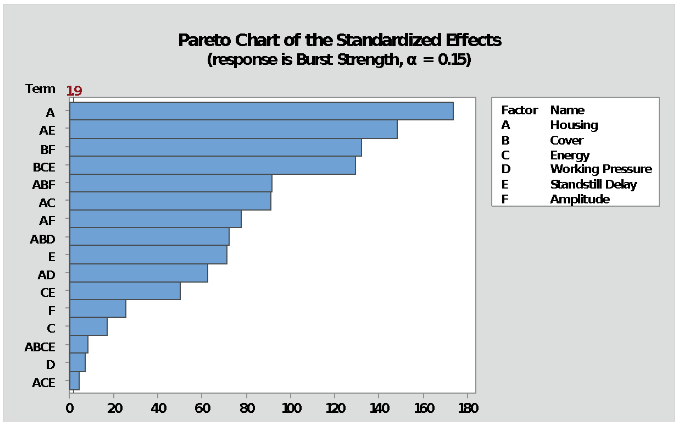

Fig. 4. Pareto chart of the standardised effects

Tab. 1. Minitab results from DoE

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.147196	100.00%	99.98%	99.58%

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		15.2750	0.0736	207.55	0.000	
Housing	25.5500	12.7750	0.0736	173.58	0.000	5.00
Energy	-1.2500	-0.6250	0.0368	-16.98	0.000	1.00
Working Pressure	-0.5000	-0.2500	0.0368	-6.79	0.007	1.00
Standstill Delay	5.2500	2.6250	0.0368	71.33	0.000	1.00
Amplitude	1.8750	0.9375	0.0368	25.48	0.000	1.00
Housing*Energy	6.7000	3.3500	0.0368	91.04	0.000	1.00
Housing*Working Pressure	-4.6000	-2.3000	0.0368	-62.50	0.000	1.00
Housing*Standstill Delay	10.9000	5.4500	0.0368	148.10	0.000	1.00
Housing*Amplitude	5.7250	2.8625	0.0368	77.79	0.000	1.00
Cover*Amplitude	-9.7250	-4.8625	0.0368	-132.14	0.000	1.00
Energy*Standstill Delay	-3.6750	-1.8375	0.0368	-49.93	0.000	1.00
Housing*Cover*Working Pressure	5.3000	2.6500	0.0368	72.01	0.000	1.00
Housing*Cover*Amplitude	6.7250	3.3625	0.0368	91.37	0.000	1.00
Housing*Energy*Standstill Delay	0.3250	0.1625	0.0368	4.42	0.022	1.00
Cover*Energy*Standstill Delay	-21.2750	-10.6375	0.0823	-129.28	0.000	5.00
Housing*Cover*Energy*Standstill Delay	-1.3750	-0.6875	0.0823	-8.36	0.004	1.00

Regression Equation in Coded Units

Burst Strength = 15.2750 + 12.7750 Housing - 0.6250 Energy - 0.2500 Working Pressure
*+ 2.6250 Standstill Delay + 0.9375 Amplitude + 3.3500 Housing*Energy*
*- 2.3000 Housing*Working Pressure + 5.4500 Housing*Standstill Delay*
*+ 2.8625 Housing*Amplitude - 4.8625 Cover*Amplitude*
*- 1.8375 Energy*Standstill Delay + 2.6500 Housing*Cover*Working Pressure*
*+ 3.3625 Housing*Cover*Amplitude + 0.1625 Housing*Energy*Standstill Delay*
*- 10.6375 Cover*Energy*Standstill Delay*
*- 0.6875 Housing*Cover*Energy*Standstill Delay*

Uncoded coefficients are not available with non-hierarchical model.

significant impact on the burst strength of the product. It also provides a regression equation for the burst strength.

From the analysis above, various burst strength settings can be achieved by modifying key input factors. One of the challenges was to create parts covering the entire operational range of the equipment. Five batches consisting of nine parts each were manufactured with each part measured for the burst strength by three different operators. The measurement results were then analysed using the Minitab Gauge R&R crossed study.

As demonstrated in Tab. 2, the total Gauge R&R % is only 2.88% of the total study variation suggesting only 2.88% of the variation coming from the measurement system and the rest from the manufacturing process. This is well below the requirement of 10%.

Furthermore, total Gauge R&R is 8.63% of the total tolerance for the burst strength. This is below the requirement of 10%, suggesting that measurement equipment can differentiate between good and bad products. The number of distinct categories was greater than five suggesting the resolution of measurement to be suitable for the application.

The R-chart by an operator in Fig. 5 shows all points within control limits suggesting no special cause and all operators performing at similar levels. From the Xbar chart in Fig. 5, one can see that mean burst strength for various test specimen vary more than the control limits. This is a desirable result, as

Tab. 2. Gauge Evaluation Results from Crossed Gauge R&R Analysis

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.28774	1.7265	2.88	8.63
Repeatability	0.28774	1.7265	2.88	8.63
Reproducibility	0.00000	0.0000	0.00	0.00
Operator	0.00000	0.0000	0.00	0.00
Part-To-Part	9.97911	59.8746	99.96	299.37
Total Variation	9.98326	59.8995	100.00	299.50

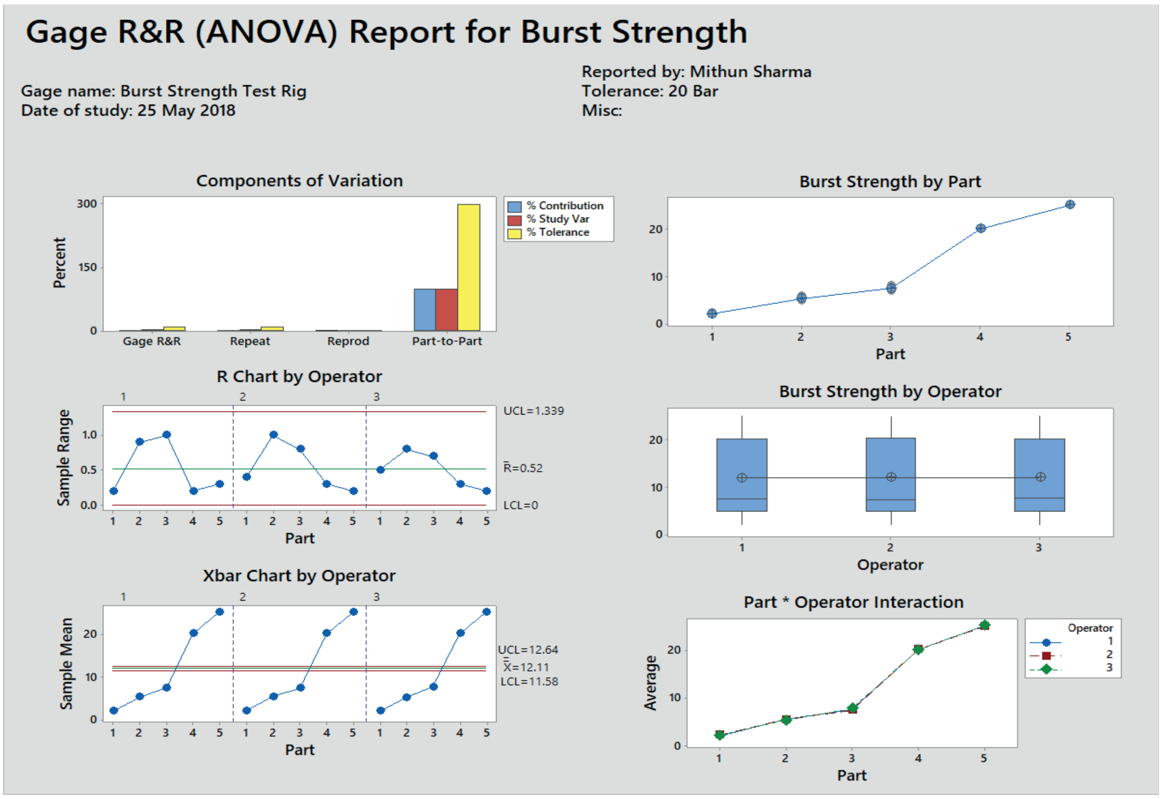

Fig. 5. Graphical results from crossed Gauge R&R analysis

the control limits are based on the combined repeatability and within-part variations. It indicates the between-burst strength differences will likely be detected over the repeatability error. The remaining charts present the burst strength by part and operator. They show a similar trend and distribution suggesting no special variation is induced due to operator; besides, the batch was homogeneous. Based on the above results, it was inferred that the burst strength test rig had passed all the internal validation requirements.

4. Discussion of the results

Key quality management systems (ISO 9001) (e.g. Zimon, 2019) and quality improvement initiatives (Six Sigma) rely on the accuracy and precision of data collection. This leads to the validation of measurement equipment using industry-standard techniques of Gauge R&R calculating measurement variation relative to process variation and process tolerance. Limited research evidence is available on the viability and relevance of the technique used for the measurement system analysis for the burst strength measurement as a destructive test (e.g. Bhakri and Belokar, 2017; Gorman and Bower, 2002; Laux, 2007; Wheeler, 1990). The current study, thus, provided novel insights into the various challenges and benefits of conducting such a design.

Test structure or plan. With destructive testing, more often than not, it will be difficult to get a large number of test specimens. It is extremely important to develop a test plan that can capture the process and measurement system variation. For Crossed Gauge R&R studies, 90 is considered to be a good number with ten parts, three operators and three repeats (10x3x3). However, considering the cost of parts being destroyed and the effort involved, for the purpose of this study, it was deemed to be impractical. Hence, the sample size was halved to 45 with five parts, three operators and three repeats (5x3x3). The current research found it to be adequate for capturing the necessary measurement equipment and process variations. The design and finding in itself can be compared to a previous research, but a much smaller number of 45 measurements, due to cost restrictions was used in the current study that yielded the same results as found by the study (Han and He, 2007) that used a much larger sample size of 72 measurements. This is a strength and novelty of this research as industries can use this knowledge to conduct cost-effective testing.

Homogeneous batches. The homogeneity of batches is absolutely critical for the successful implementation of the Crossed Gauge R&R study as have been consistently emphasised in previous literature sources (e.g. Gorman and Bower, 2002; Mast and Trip, 2005) and research studies (Han and He, 2007; Phillips et al., 1997). Findings of the current study supported those inferences relating to the homogeneity of batches. Otherwise, validation efforts are likely to fail. It is important to know that repeatability includes the within batch variation, and if batches are not homogenous, measurement equipment is likely to fail the validation. In the current research, the repeatability percentage was 8.63, which was close to the acceptability limit of 10%. Based on prior experience with the product and controlled laboratory testing, in the within batch variation was deemed to be approximately 2% out of the 8.63% repeatability, noticed during the crossed Gauge R&R. It is advisable to not base any significant interpretations solely on repeatability numbers. Furthermore, in line with Han and He's research, it was found that caution must also be exercised with respect to the within batch variation, in the case the repeatability exceeds the acceptable limit.

Process knowledge. Initial exercise of DoE was extremely useful in developing knowledge about the ultrasonic welding process and characterising the key input variable that affects the burst strength of the product. This proved to be effective in creating homogeneous batches across the entire operational range. It also helped in critically analysing the result of the Gauge R&R study and not accepting them on face value. A novel finding from the current research was that it went beyond the relevance of homogeneous batches; additional evidence on the exploration of tools and techniques that can be used to develop homogenous batches was also revealed through current research findings.

The utility of the range chart. The first iteration of the Gauge study failed the repeatability condition. Out of control points in the range control chart at high burst strength (> 16 bar), testing indicated an occurrence of something unusual at high pressure. Further investigation revealed that the test housing that held the cartridge was slightly bigger, resulting in leaks at higher pressure before the cartridge could break. Correct burst strength results were achieved once the cartridge housing was modified. The current study supported the utility of the Range chart as conducted by other researchers (Bhakhri and Belokar, 2017; Diering et al., 2015).

Observations must be recorded. In line with previous literature (AIAG, 2002), the recording of observations was found to be of high relevance as tests were destructive, and measurements could not be repeated. On several occasions, anomalies were found in data, where a seal was found to be split after the test, resulting in a lower than normal value of the burst strength. Based on the observation, these values were safely ignored, and the test could be repeated, with the same settings.

The need to examine the experiment execution in destructive testing. Similar to analysis studies of the non-destructive measurement system, it was observed that extra vigilance was required for executing the Gauge R&R study. There was a need to randomise the runs with a clear statement of the purpose for the execution of the measurements. These findings corroborated the results found in the previously published literature (AIAG, 2002).

Cost vs value. In the current study, the cost of poor quality could be 1/10 000 of the cost of a part. So, it was reasonably easy to justify the cost of wasting 45 parts to validate the measurement system and prevent the cost of poor quality. However, this may not be possible in every case, and for those cases, the value of destructive testing in the first place should be questioned and, if possible, alternate testing/measurement methods should be found.

Conclusions

The following conclusions can be drawn from this study:

- The use of the Crossed Gauge R&R analytical tool was found to be useful as a means of validating the burst strength test equipment that uses destructive testing. However, it should be used as an aid rather than the solution for the validation of a measurement system.
- Well documented validation criteria existed for most measurement equipment, except for the burst strength test equipment as it involved destructive testing (Mast and Trip, 2005).

It should be noted that the biggest challenge in a destructive Gauge R&R study is an estimation of the within batch variation, which was also encountered in the current study. However, the in-depth knowledge of manufacturing processes and measurement equipment were helpful in overcoming this limitation in the current research. The applicability of this research is thus limited to similar settings only, as it may be equally challenging to conduct Gauge R&R for a new measurement system or a manufacturing process in a different context. It will, therefore, be useful for future research to develop a more general statistical method for calculating the within batch variation for the measurement system using destructive testing.

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Volume 11 • Issue 4 • 2019

Engineering Management in Production and Services

sciendo

received: 10 April 2019
accepted: 15 November 2019

pages: 43-53

Towards organisational simplexity — a simple structure in a complex environment

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ABSTRACT
The article contributes to the discussion on the validity and ways of simplifying modern organisations. There is an increasing focus on simplifying organisations, especially their organisational structures. However, the environment of contemporary organisations is increasingly complex, dynamic and uncertain. Therefore, the postulate of simplicity seems to question Ashby's law stating that one kind of variety must be balanced by a different kind of variety. To cope with the indicated discrepancy, it is assumed that the simplification of some elements of an organisation is only possible due to the excessive complexity of others. The paper aims to verify the concept of organisational simplexity developed by e Cunha and Rego, which postulates the fit between simple structural solutions, complex workforce and complex environment. However, organisational performance is a factor verifying the legitimacy of the fit. The literature study explored the contradiction inherent in the postulate on the simplification of modern organisations. The contingency theory provided a major framework for the study. The research hypothesis was developed and empirically verified. The empirical study targeted 1142 organisations operating in Poland and Switzerland, different by their industry, size and the form of ownership. To verify the hypothesis, a statistical analysis was carried out, and the multiple correspondence analysis (MCA) method was used. The main result of the critical literature analysis is the finding that theoretical indications for simplifying modern organisations are fragmented, mainly focused on simplifying selected elements of an organisation, not considering the contradiction inherent in the postulate of simplicity related to environmental features and not verified empirically. The notion of the simplexity has been adopted, and it treats the simplicity and complexity as interrelated issues conditioned by situational factors. According to the empirical research results, the fit has been revealed between the degree of structure simplicity, the workforce complexity and the environment features.

KEY WORDS
complexity, organisational structure, organisational performance, simplexity, simplicity, workforce, contingency approach

DOI: 10.2478/emj-2019-0032

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Introduction

The quest for simplicity as an act of opposition to the complexity of the world of organisation and management is becoming more visible (Hopej et al., 2017). It is not surprising, as several empirical studies deliver hard data proving that excessive complexity of an organisation has a significant negative impact on productivity, profits, the level of customer service, corporate governance and product development (Collinson & Jay, 2012; Leff & Zolkos, 2015). However, the research conducted by The Economist shows that modern organisations are perceived by managers as too complex: almost half of 331 managers stated that their organisations were very or extremely complex — even too complex to manage (Leff & Zolkos, 2015). What is more, the organisational complexity seems to be increasing even though for almost two decades, the management tools and some more comprehensive concepts of simplifying organisations have been developing (e.g. Eisenhardt & Sull, 2001; Maeda, 2006; Ashkenas, 2007; Osbert-Pociecha, 2013; Collinson & Jay, 2012; Segall, 2013; Brandes, 2013; Hopej et al., 2017).

The question arises why the efforts to simplify organisations do not bring the expected results? It is argued that there is an unresolved contradiction in the postulate of the organisational simplification as it questions Ashby's law (Cunha & Rego, 2010; Hopej-Kamińska et al., 2015; Hopej et al., 2017). Modern organisations function in an increasingly more complex, dynamic and uncertain environment. Therefore, according to Ashby's law stating that one kind of variety must be balanced by a different kind of variety, modern organisations should be increasingly more complex (not simple!). As a result, any concept of simplifying organisations or simplifying any element of an organisation (e.g. organisational strategy, structure, processes or products offered) must face this contradiction.

The article uses the adapted concept of organisational simplexity developed by e Cunha and Rego (2010), as it seems to cope adequately with the indicated discrepancy. The authors argue that the complexity and simplicity should permeate each other for an organisation to gain a competitive advantage and achieve success. According to Cunha and Rego (2010), when the complexity of the environment is increasing, the simplification of some elements of an organisation is only possible due to the excessive complexity of others. In particular, they postulate the necessity of the fit between the degree of organisational structure simplicity, the workforce complexity and the complexity of the organisational environment. The concept of organisational simplexity is very promising, as it supports the simplification of some elements of an organisation operating in a complex environment (according to business practitioners' expectations) and it is in line with Ashby's law. In this paper, the attempt to verify the concept of organisational simplexity has been made. A question emerges: Is there a fit between the simplicity of the organisational structure, workforce complexity and selected features of the organisational environment (complexity, dynamics and uncertainty)? In other words, is it justifiable to formulate such a concept as organisational simplexity? Therefore, this paper mainly aims to verify the proposed concept of simplexity and confirm that such a fit (simplexity) leads to enhanced organisational performance.

The perspective of the contingency theory is adopted since it assumes that enhanced organisational performance results from fitting organisational features to contingencies that reflect the situation of the organisation (Donaldson, 2001; Hamann, 2017; McAdam et al., 2019). Two main courses of research are considered: the internal fit between organisational characteristics (e.g., organisational strategy, structure, culture, human resource management system or technology), and the fit between organisational and environmental features (Burns & Stalker, 1961; Donaldson, 2006; Hamann, 2017; McAdam et al., 2019).

The empirical research involved 1142 organisations operating in Poland and Switzerland. The multiple correspondence analysis (MCA) was used to reach the set aim.

1. Concept of the organisational simplexity

It is hard to achieve simplicity in a complex world. Moreover, complexity theorists note that complexity arises from simplicity (Gribbin, 2004). Cunha and Rego (2010) underlie the evolution of organisational thinking into a paradoxical combination of simplicity and complexity, which should permeate each other for an organisation to gain a competitive advantage and achieve success. The concept of simplexity is a compromise that allows combining simplicity (of the structure) and complexity (of the workforce). Authors focus on how a simple design may facilitate the emergence of complex and adaptive collective behaviour (in coexistence and co-evolving). Therefore, two elements will be considered: organisational structure and workforce, underlining that the simplicity of one and the complexity of the other can result in some benefit for organisations.

1.1. Simple structure solution

The organisational structure emerges as one of the main sources of the excessive complexity of an organisation (Collinson & Jay, 2012; Leff & Zolkos, 2015). It is increasingly emphasised that simple structural solutions support flexibility and adaptation of organisations operating under complex, dynamic and unpredictable conditions (Drucker, 1993; Peters & Waterman, 2004; Welch & Welch, 2005; Ashkenas, 2007; Cunha & Rego, 2010; Leff & Zolkos, 2015), yet the existing structural solutions do not meet the criterion of simplicity. For example, in already cited research of The Economist, more than a half of the managers perceived the structure of their organisations as very or extremely complex, and only 1% of them found the structure to be sufficiently simple (Leff & Zolkos, 2015). The very concept of a simple structure is still ambiguously understood (Hopej-Kamińska et al., 2015). Therefore, the term will be approximated in the context of different and often conflicting views.

In the literature, the most frequently referenced model of a simple structure has been developed by Mintzberg (1979). It is characterised by a flat, two-tier hierarchy, low degree of specialisation, formalisation and standardisation activities as well as a high degree of centralisation. Such a structural solution can be seen as restrictive because within it, one person sets the rules of action for the rest to follow. Therefore, there is little room for manoeuvre. Mintzberg's concept of a simple structure is centred around environmental complexity reduction where "the organisation tries to simplify and reduce the amount of data and the number of choices available to its members. Sense-making is undertaken by only a few agents whose roles place them at the top of the hierarchy" (Ahmos et al., 2002, p. 193). Miller (1993) and Lumpkin and Dess (1995), who share this understanding of a simple structure, also claim that it is not the best solution under complex and changing environmental conditions.

However, a different approach is also present in the literature. Hopej-Kamińska et al. (2015) argue that a simple structural solution is the one, which maximises the freedom of organisation's members. Using fractal calculus, they verified and confirmed the developed concept. Ahmos et al. (2002) emphasise that in the face of increasing environmental complexity, an organisation can not only strive to reduce this complexity but also to absorb it. An organisation must "hold multiple and sometimes conflicting representations of environmental variety, retaining in their behavioural repertoire a range of responses, each of which operates at a lower level of specificity" (Ahmos et al., 2002, p. 193). In such a case, "the simplicity of the structural solution boils down to the limitation and simplification of all top-down imposed rules" (Hopej-Kamińska et al., 2015, p. 264). Hence, the simple structure is a flat structural solution, characterised by a small number of hierarchical levels and a large span of control, low degree of centralisation, formalisation, specialisation and standardisation (Hopej-Kamińska et al., 2015). The second approach is in line with those adopted by Cunha and Rego (2010) in their simplexity concept.

1.2. Complex workforce

According to Cunha and Rego (2010), when the complexity of the organisational environment increases, the structure simplicity comes at the expense of the complexity of other elements in the organisation (which together create some sort of balance needed for the organisation to operate). This notion supports the consistency between the postulate of organisational simplification in the complex world and Ashby's law. It is also is in line with the contingency approach. Discussing the complexity theory in the context of an organisation, Marion (1999, pp. 81-82) adapted the concept of Complex Adaptive Systems (CAS), which is "an adaptive, interactive network of actors (...) structured by physics and teleology (…) refined by selection." This idea can be referenced to the world of organisation where adaptation to the complex environment through simple structure may occur only based on that interactive network of actors, i.e. complex workforce. Moreover, they state that there is a need for some sort of compromise between the simplicity of structure required to adapt to the contingency of the organisational environment and the fact that it should be obtained by internal differentiation — workforce complexity. Also, Cunha and Rego (2010) suggest that it should be clear that the balance can be achieved by connecting a simple organisational structure with a complex workforce, which cannot be avoided in today's world.

It seems to be important to focus on what is workforce complexity. Hase (2002) underlines that the capability of employees should be a goal for every organisation and simultaneously, it is one of the greatest sources of complexity in an organisation. Stephenson and Weil (1992, p. 2) emphasise that it "is not just about skills and knowledge. Taking effective and appropriate action under unfamiliar and changing circumstances involves judgements, values, the self-confidence to take risks and a commitment to learn from the experience." Therefore, it can be said that nowadays, it is almost impossible to secure organisation operations and competitive advantage without such a complex workforce, which is not only characterised by competence but also by capability. The Complexity Theory underlines the importance of being ready for sudden, unaccountable change at any moment and the need for relying excessively on prediction (Hase, 2002; Bieńkowska & Tworek, 2019). It seems that in the complex environment, the simplification of the organisational structure must be balanced by the complexity of workforce organised based on this structure. Organisations competing based on simple designs, accept that they may have to cope with external turbulence and flexible networks of highly autonomous individuals and teams as well as by stimulating intrapreneurship (Cunha & Rego, 2010). Moreover, thanks to competence and capability, the complex workforce can undertake risk and work efficiently, even in a changing environment. Highly talented people do not need, and are unlikely to put up with, an overtly hierarchical management model (Hamel, 2008). Provided with possibilities to participate, they can become change agents. It is a complex workforce that enables adaptive management in a way absorbing a part of outer variability as long as the organisational structure allows.

Therefore, in the context of the above-mentioned literature review, it seems justified to propose the following hypothesis:

H: The fit between the simplicity of the organisational structure, workforce complexity and selected features of the organisational environment (complexity, dynamics and uncertainty) positively affects the organisational performance.

It has been decided that verification of organisational simplexity concept must be widened and will apply not only to the fit between the simplicity of the organisational structure, workforce complexity and the organisational environment. It has been recognised that organisational environment characteristics have to have a wider perspective because today's organisational world is increasingly more complex and also volatile and, therefore, unpredictable. Moreover, it is crucial to establish the verifying criteria of fit validity, such as organisational performance.

2. Research methodology

To verify the hypotheses, a questionnaire was used to conduct a survey. The main survey was preceded by the pilot survey conducted in early 2018, in a group of 50 organisations, to explain the issues concerning the ambiguity of questions. According to the obtained results, the ambiguous questions were rewritten to obtain more informed responses from organisations participating in the main survey. The main research was conducted as a part of a research project No. 2017/01/X/HS4/01967 — "The influence of IT reliability on the quality of management methods and techniques", financed from the funds of the National Science Centre of Poland. It was carried out in March 2018, in a group of organisations located in Poland and Switzerland, which was the only condition limiting the sample (organisations were surveyed regardless of their size, industry or the type of business). Online survey service SurveyMonkey was used. The respondent panel of managers working in organisations of both countries was purchased and used as a poling sample for the research. 558 valid responses were collected from Poland and 564 — from Switzerland. Respondents were asked to evaluate several organisational issues based on the list of factors using the five-level Likert scale for the measurement of (on the scale from "I strongly disagree" to "I strongly agree" with the middle point "I do not have an opinion"):

- structure simplicity measured based on the item: "Organisational structure of the company is simple";
- workforce complexity measured based on the item: "Employees are independent, proactive and open to new ideas".
- environmental characteristics were also evaluated using the same five-level Likert scale for:
- environmental complexity based on the item: "Company offers different products or services";
- environmental dynamics based on the item: "Company's environment is constantly changing";
- environmental unpredictability based on the item: "Changes in the company's environment are unpredictable."

Since the performed research was intended as a pilot, it was consciously decided to measure each of the phenomena using the one-item technique. Such an approach is valid and can be found in the literature concerning the methodology of research in management sciences (e.g. Fuchs & Diamantopoulos, 2009).

The organisational performance scale was an exception, as it was based on nine items (return on investment (ROI), sales growth, profit growth, productivity improvement, reduction of emissions, effluent & waste, reduced use of resources (key materials/energy/water), improvement of employee satisfaction, improvement of health and safety conditions, the impact on the creation of healthy and liveable communities) and captured the extent, to which organisation achieved organisational performance, including financial and non-financial measures and short-term and long-term measures, covering financial and market performance, quality performance and innovation performance (Crane et al., 2014; Campos et al., 2015; Maletic et al., 2015; Matić, 2012).

The evolution of the performance during the previous three years was conducted. Respondents were asked to rate the performance using the Likert scale (from "well below expectations" to "well above expectations" with the middle point being "as expected"). In line with the literature, subjective measures of organisational performance were used (Maletic et al., 2015).

The study was based on the 5-point Likert scale due to several reasons. First, the odd-numbered scale was chosen to not force respondents to have a definite opinion, which could have reduced the chance for response bias in social sciences studies (Croasmun & Ostrom, 2011). Second, 5-point scales are known to have higher scale reliability than those that have 3 points (Hartley, 2014).

To verify the hypothesis, a statistical analysis was carried out. A correlation analysis was performed to initially verify the relationships between the simplicity of the organisational structure and the complexity of the workforce under the conditions of a complex, dynamic and unpredictable environment. As the investigated relationship was initially confirmed, an in-depth analysis was conducted using the multiple correspondence analysis (MCA) method.

3. Research results

It was assumed that the structure of the relationship between the workforce and the environment must be verified in the context of organisational performance. The verification of the simplexity concept is based on the use of organisational performance as a dependent variable while remaining variables are treated as independent variables. Tab. 1 contains descriptive statistics for all measured variables.

Tab. 1. Descriptive statistics

	N	Min	Max	Mean	Std. deviation
Environmental dynamics	1142	1.00	5.00	3.07	1.224
Environmental unpredictability	1147	1.00	5.00	3.10	1.163
Environmental complexity	1145	1.00	5.00	3.04	1.214
Structure simplicity	1146	1.00	5.00	3.03	1.190
Complex workforce	1141	1.00	5.00	3.03	1.191
Organisational performance	1120	1.00	5.00	3.33	0.921

Tab. 2. Analysis of the correlation between environment features, the structure simplicity and the workforce complexity (the Spearman's Rho correlation test)

		Structure simplicity	Complex workforce	Environmental dynamics	Environmental unpredictability	Environmental complexity
Structure simplicity	Correlation	1.000	0.590**	0.586**	0.551**	0.509**
	Sig. (2-tailed)	.	0.000	0.000	0.000	0.000
	N	1146	1138	1139	1143	1142
Complex workforce	Correlation	0.590**	1.000	0.635**	0.525**	0.602**
	Sig. (2-tailed)	0.000	.	0.000	0.000	0.000
	N	1138	1141	1135	1139	1136
Environmental dynamics	Correlation	0.586**	0.635**	1.000	0.689**	0.583**
	Sig. (2-tailed)	0.000	0.000	.	0.000	0.000
	N	1139	1135	1142	1140	1137
Environmental unpredictability	Correlation	0.551**	0.525**	0.689**	1.000	0.573**
	Sig. (2-tailed)	0.000	0.000	0.000	.	0.000
	N	1143	1139	1140	1147	1142
Environmental complexity	Correlation	0.509**	0.602**	0.583**	0.573**	1.000
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	.
	N	1142	1136	1137	1142	1145

**. Correlation is significant at the 0.01 level (2-tailed)

3.1. Correlation analysis

The coefficients of correlation between environmental features, the structure simplicity and the workforce complexity were calculated (Tab. 2).

The results show that the variables are significantly correlated, and the correlation is moderate. It means that the growing structure simplicity is accompanied by the growth of workforce complexity and, at the same time, the growth in complexity, dynamics and unpredictability of the organisation's environment.

3.2. Multiple correspondence analysis model

The multiple correspondence analysis (MCA) is an exploratory technique for categorised variables. It allows creating models of links between different categories of answers. In the case of the study, the analysis allows determining the strongest related variables (response categories) with the study group. As the impact force classifier, the model of distance maximisation from the reference point (the study group) was adopted. Because the main interest was the correspondence with the study group, the points in space for the three studied groups were taken as reference points for other points (responses) and the quality of the solution.

In the MCA model, the division into low, average and high variable results was determined based on a standardised distribution N (0;1). Values <-1 to low values (L), >1 high values (H) and from -1 to 1 average values (A).

The variable Simplexity (Sim) was established. It had 6 values: 0, 1, 2, 3, 4, 5. Each independent variable

Tab. 3. Multiple correspondence analysis model MCA

	Code	Mass	Quality	Relative inertia	Factor 1			Factor 2		
					Coordinates	Absolute inertia	Cos2	Coordinates	Absolute inertia	Cos2
Environmental dynamics	Ed:L	0.014	0.696	0.053	-1.400	0.047	0.211	2.121	0.128	0.485
	Ed:H	0.022	0.622	0.050	1.698	0.111	0.535	0.688	0.022	0.088
	Ed:A	0.107	0.609	0.015	-0.173	0.006	0.089	-0.420	0.039	0.520
Environmental unpredictability	Eu:L	0.013	0.691	0.054	-1.419	0.044	0.197	2.247	0.132	0.494
	Eu:H	0.022	0.644	0.050	1.747	0.114	0.547	0.737	0.024	0.097
	Eu:A	0.108	0.638	0.014	-0.183	0.006	0.105	-0.411	0.038	0.533
Structure simplicity	S:L	0.015	0.593	0.053	-1.244	0.041	0.186	1.841	0.106	0.407
	S:H	0.021	0.576	0.050	1.676	0.101	0.481	0.743	0.024	0.095
	S:A	0.107	0.561	0.015	-0.150	0.004	0.066	-0.410	0.037	0.495
Environmental complexity	Ec:L	0.016	0.597	0.052	-1.302	0.047	0.213	1.747	0.100	0.384
	Ec:H	0.023	0.518	0.049	1.513	0.089	0.433	0.671	0.021	0.085
	Ec:A	0.104	0.508	0.016	-0.131	0.003	0.046	-0.414	0.037	0.462
Complex workforce	Cw:L	0.014	0.594	0.053	-1.365	0.045	0.205	1.882	0.103	0.389
	Cw:H	0.023	0.587	0.050	1.628	0.103	0.498	0.687	0.022	0.089
	Cw:A	0.106	0.534	0.015	-0.165	0.005	0.078	-0.397	0.034	0.456
Simplexity	Sim:0	0.054	0.342	0.036	-0.725	0.049	0.322	0.181	0.004	0.020
	Sim:1	0.021	0.048	0.050	-0.331	0.004	0.019	-0.401	0.007	0.028
	Sim:2	0.023	0.034	0.050	-0.047	0.000	0.000	-0.426	0.008	0.034
	Sim:3	0.015	0.038	0.053	0.475	0.006	0.027	-0.316	0.003	0.012
	Sim:4	0.010	0.094	0.055	1.080	0.021	0.090	0.232	0.001	0.004
	Sim:5	0.019	0.409	0.051	1.522	0.077	0.360	0.560	0.012	0.049
Organisational performance	Op:L	0.019	0.238	0.051	-0.862	0.024	0.112	0.916	0.032	0.126
	Op:H	0.028	0.413	0.047	1.047	0.052	0.263	0.790	0.035	0.150
	Op:A	0.096	0.376	0.019	-0.133	0.003	0.037	-0.404	0.032	0.340

was categorised: values 1, 2, 3 were given 0, and values 4, 5 were given 1. Hence, the sum was just the sum of 1s. If among 5 variables, the chosen values were 4 or 5, the sum was 5. In the case all variables were below 4, the sum was 0.

The results of the MCA analysis are presented in the Tab. 3. The chosen model is statistically significant: Chi2(529) = 38898; $p < 0.01$.

The MCA model shows several significant findings. Firstly, in accordance with all independent variables (structure simplicity, workforce complexity and all three environmental characteristics), for each of them, the low values were accompanied by the low values of others (and similarly for medium and high values). Therefore, the following conclusions can be made:

- in the dynamic, complex and unpredictable environment, there is a concomitance between structure simplicity and complex workforce;
- in a stable, simple and predictable environment, the opposite situation occurs: the complex structure is accompanied by a simple workforce;
- medium average environment characteristics coexist with a medium level of structure simplicity and workforce complexity.

Secondly, the high value of independent variables is accompanied by a high level of organisational performance (and similarly for medium values). It can, therefore, be underlined that there is a relationship between variables of the simplexity (Sim) and the organisational performance (Op). It has been arbitrary established that organisational performance is a dependent variable. When simplexity reaches the level of 4 or 5, the organisational performance also reaches high values, while 0 to 3 values for simplexity level indicate average organisational performance. That is a particularly interesting result that means that although there is the fit between structure simplicity, complex workforce, environmental dynamics, unpredictability and complexity, such fit does not necessarily lead to higher organisational performance. Therefore, the obtained results are not sufficient to accept the proposed hypothesis.

Discussion

The empirical results are inconclusive, and do not allow for the unambiguous acceptance of the research hypothesis H: The fit between the simplicity

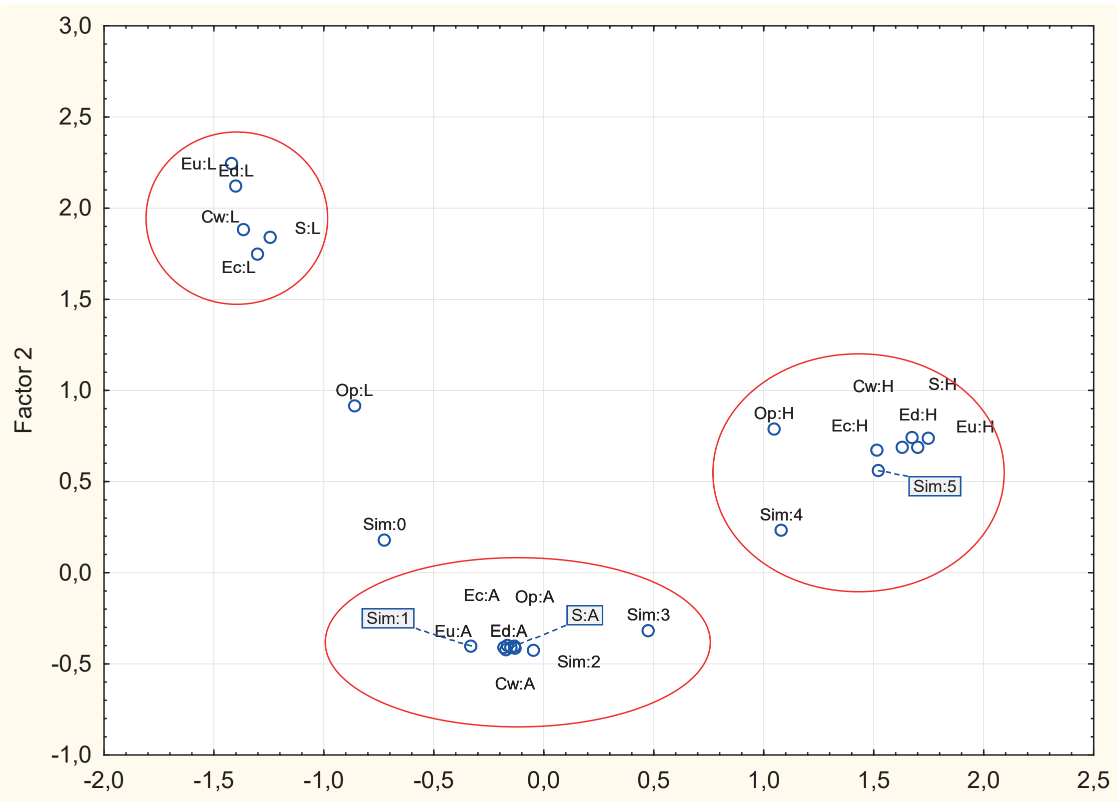

Fig. 1. Chart of projection of multidimensional space of MCA characteristics into a two-dimensional space

of the organisational structure, workforce complexity and selected features of the organisational environment (complexity, dynamics and uncertainty) positively affects the organisational performance. The hypothesis was confirmed only for organisations operating in a highly dynamic, complex and unpredictable environment.

A significant fit was established between the structure simplicity and the workforce complexity in examined organisations, adequate to environmental features. A more complex, dynamic and uncertain environment aligned with more complex workforce and simpler structural solutions. Therefore, the organisational simplexity concept by Cunha and Rego (2010) was empirically proven. However, the study results should be related to the core elements of the contingency theory. Not only the contingency factor and the organisational system must be associated (and a change in the contingency factor must cause a change in the organisational system), but also a fit between the contingency factor and the organisational system should positively affect the performance of this system (Donaldson, 2001; Harmann, 2017). Although there is a fit between studied organisational characteristics (structure simplicity and workforce complexity) and organisational environment features (complexity, dynamics and uncertainty), only in the case of a highly complex, dynamic and uncertain environment, this fit leads to high organisation performance. The results are inconclusive for other types of environment. Therefore, the study can bring direct recommendations only for organisations operating in a complex, dynamic and uncertain environment. Considering that most contemporary organisations operate in such conditions, the obtained results seem to fill an important research gap.

The research results support the concept of a simple structural solution that is centred around the absorption of the environmental complexity rather than its reduction. Accepting that the organisational structure is as a set of rules ordering the behaviour of the organisation's members (Hopej-Kamińska et al., 2015), it can be stated that the simpler is the structural solution, the more freedom it gives organisational members (and the fewer restrictions it imposes on them). It is in line with the views on the concept of a simple organisational structure of such authors as Ahmos et al. (2002), Cunha and Rego (2010) or Hopej-Kamińska et al. (2015). However, it is in contrary to classical views of Miller (1993), Lumpkin and Dess (1995) or, in the centralisation dimension, to the Mintzberg (1979) concept of a simple structure. The research supports the first approach, as it was proven that in surveyed organisations, the more complex (and also more dynamic and uncertain) organisational environment was coexisting with simpler organisational structures. Traditionally, authors consider the simple structure as appropriate mainly for young organisations, which are rather small. It would be important to incorporate the size and the age of organisations to further research the relationship between the structure simplicity and environmental features.

The conducted research shed some new light on strategies, methods and tools aimed at simplifying organisations (e.g. Ashkenas, 2007; Collinson & Jay, 2012; Segall, 2016; Bodell, 2016) and organisational elements (e.g. Eisenhardt & Sull, 2001; Peters & Waterman, 2004; Maeda, 2006; Ashkenas, 2007; Osbert-Pociecha, 2013; Segall, 2013; Brandes, 2013; Hopej et al., 2017) proposed by various authors.

First, most studies to date are dominated by the focus on simplifying organisations in all considered dimensions, they abstract from the relationship between various aspects of an organisation, and also from the external organisational context (e.g. Ashkenas, 2007; Leff & Zolkos, 2015; Segall, 2016). The presented research shows that the concept of organisational simplicity cannot concern the simultaneous simplification of all elements of an organisation. This result is in line with Ashby's law and means that simplifying certain aspects of an organisation requires an increase in the complexity of others, always in the context of the organisation's environment. According to the study, the simplification of the organisational structure must be accompanied by conscious efforts to develop staff competences so that employees can behave freely and efficiently while undertaking necessary decisions and actions. This result, although limited only to few organisational simplicity elements, reveals that the organisational simplicity concepts and methods formulated so far must be verified. The notion of organisational simplicity is not that simple. To conceptualise it, extended research is required, i.e. research verifying the relationship between the simplicity of different organisational elements and organisational simplicity and organisational performance in different business contexts.

Most proposals in the field of organisational simplicity are of a theoretical nature, possibly supported by case studies. The extended empirical research is very limited, mainly the studies of Leff and

Zolkos (2015), Kamińska-Hopej et al. (2015) and Collinson and Jay (2012). The research presented in this article may enrich the results obtained by other authors, open new research directions and even, to some extent, undermine some results.

Leff and Zolkos (2015) examined the views of managers regarding the causes of excessive complexity, ways of dealing with them and ways of measuring results of encouragement. However, they did not refer to the relationship between various dimensions of simplicity, nor did they consider the external context of the organisation's operations.

Hopej-Kamińska et al. (2015) focused on the problem of simplifying the organisational structures, and they conducted a pilot study on a sample of 100 Polish organisations. The study demonstrated that the simplicity of the structure was correlated with the size of the organisation, the diversification of the activity, the manufacturing technology, the strength of the relations of the organisation with the environment, corporate culture as well as with the management's attempts to simplify the organisation. The current research is an extension of those obtained by Hopej-Kamińska et al. Not only it proves that there is a significant relationship between the simplicity of the organisational structure and the workforce complexity (a factor not included in the quoted study). Moreover, based on the contingency approach, the relationship was identified to organisational performance in the context of different situational conditions. The presented research, along with those carried out by Hopej-Kamińska et al. (2015), may be a starting point for further research: both studies contribute to the development of knowledge about the relationship between the level of simplicity of various organisational elements and organisational environment, and the study described in this article additionally indicates the importance of compatibility between different elements of an organisation and its environment with regard to their simplicity/complexity.

A reference should also be made to the results of empirical studies conducted by Collinson and Jay (2012). These researchers were the only ones who conducted in-depth empirical research into the relationship between the organisational complexity (they treated simplicity as the opposite of complexity) and organisational performance. Six dimensions of complexity were distinguished: one external (environmental complexity) and five internal (product, strategy, people, design and process). 200 organisations form Global Fortune 500 were analysed according to their complexity and performance. Collinson and Jay (2012) found that the relationship between performance and complexity is best characterised by an inverted-U-shaped curve. As a result, they distinguished two types of organisational complexity: good and bad. Good complexity creates additional value (performance increases as complexity increases), bad complexity increases cost and destroys value (performance decreases as complexity increases). The main result of the research by Collinson and Jay (2012) is the formulation of simplification strategies (related to complexity dimensions) focused on unleashing organisational performance. The quoted study stands out in terms of the adopted research method and of relating the concept of organisational simplicity/complexity to organisational performance. They also recognise that organisations can be not only too complex but also not complex enough. At the same time, due to theoretical assumptions, they clearly follow the dominant approach of the simultaneous simplification of all elements of an organisation (dimensions of organisational complexity). It should be emphasised again that the empirical research described in this article proves that the concept of organisational simplicity cannot mean the simultaneous simplification of all elements of an organisation. In this context, the interpretation of the inverted-U-shaped curve, showing the relationship between performance and complexity, developed by Collinson and Jay (2012), should be considered. The inverted-U-shaped curve may mean that for other situations than 'optimal', according to Collinson and Jay (2012) (when the level of complexity relates to the highest level of performance), the fit between external conditions and internal dimensions of complexity is not appropriate, or the fit between complexity of different internal organisational elements is not appropriate. For example, in relation to the performed research, the simultaneous increase in the simplicity of organisational structure and workforce would not have a positive effect on organisational performance (the performance would be the highest for average structure and workforce complexity). From this perspective, the presented research prompts to reconsider the results obtained by Collinson and Jay (2012).

Hence, the final theoretical implications of the presented research may be formulated. The concept of organisational simplexity is more promising than the notion of organisational simplicity or organisational complexity, as it reveals the need to adjust the level of simplicity and complexity of various elements of an organisation. Wherein, the reconceptualization of organisational simplexity is required as adapting only two organisational elements proposed by Cunha and Rego (2010) is not sufficient. First, no significant correlation between the adapted concept of organisational simplexity and organisational performance for other than the most complex, uncertain and unpredictable environmental conditions, calls for reconceptualization. Secondly, several factors are considered in the literature as important for the notion, among others: organisational strategy, leadership style, technology, culture, processes, information technology (Maeda, 2006; Ashkenas, 2007; Collinson & Jay, 2012; Osbert-Pociecha, 2013; Segall, 2013; Brandes, 2013; Kamińska-Hopej et al., 2015; Segall, 2016; Bodell, 2016; Hopej et al., 2017). It must be emphasised that any research on the concept of simplexity should be embedded in the contingency theory. It allows for the integration of seemingly contradictory efforts to increase the simplicity of certain elements of the organisation and at the same time, increase the complexity of others. Additionally, the contingency theory supports the rejection of perceiving the organisational simplicity as an unquestioned value and aim and accepting that the level of organisational simplicity/complexity must be related to the positive organisational effectiveness.

The limitations of the research must be pointed out. According to the contingency theory, several endogenous and exogenous factors could be included in the survey. However, the study was limited only to two organisational characteristics and three environmental features, since the main aim of the paper was to empirically verify the concept of organisational simplexity. The empirical research also has its limitations. It was performed only in two business contexts (Poland and Switzerland) and requires further analysis. Although every effort was made to ensure that the respondents have extensive knowledge about the operations of the organisation (the sample was limited to managers), it would be important to expand the research in the future using other measurement methods of considered issues (e.g. organisational document analysis, surveys of different groups of employees, KPIs). Finally, the research was carried out only one time in each organisation. Since, according to the contingency approach, interaction fit is particularly important, it requires conducting a longitudinal survey, and it seems that further studies are also required.

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Volume 11 • Issue 4 • 2019

sciendo

International Society for Manufacturing, Service and Management Engineering

received: 15 June 2019
accepted: 15 October 2019

pages: 54-64

Logit business failure prediction in V4 countries

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ABSTRACT
The paper presents the creation of the model that predicts the business failure of companies operating in V4 countries. Based on logistic regression analysis, significant predictors are identified to forecast potential business failure one year in advance. The research is based on the data set of financial indicators of more than 173 000 companies operating in V4 countries for the years 2016 and 2017. A stepwise binary logistic regression approach was used to create a prediction model. Using a classification table and ROC curve, the prediction ability of the final model was analysed. The main result is a model for business failure prediction of companies operating under the economic conditions of V4 countries. Statistically significant financial parameters were identified that reflect the impending failure situation. The developed model achieves a high prediction ability of more than 88%. The research confirms the applicability of the logistic regression approach in business failure prediction. The high predictive ability of the created model is comparable to models created by especially sophisticated artificial intelligence approaches. The created model can be applied in the economies of V4 countries for business failure prediction one year in advance, which is important for companies as well as all stakeholders.

KEY WORDS
logit, business failure, financial ratios, prediction model, V4 countries

DOI: 10.2478/emj-2019-0033

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Introduction

Financial risk is the possibility that company shareholders will lose money if the corporate cash flows are not sufficient to meet financial obligations. Business failure prediction models are used to eliminate this potential risk. Their task is to evaluate the financial health of the company based on selected financial indicators or other characteristics of the company or the environment in which they operate (Kovacova and Kliestik, 2017).

The main aim of the paper is to present the business failure prediction model for companies that operate in the economics of the Visegrad Group (V4). V4 is a cultural and political alliance of four Central European states — the Czech Republic, Hungary, Poland, and Slovakia. It was established to advance military, cultural, economic and energy cooperation among the countries, also furthering their integration in the EU. All V4 nations are post-communist countries with high-income and more or less steady economic growth over the last decades (Visegrad Group, 2019). In these countries, foreign models or national models have been used for business failure prediction. However, generally, they were unaccepted because foreign models tend to be less predictive, and national models have often been developed for specific economic sectors (Kliestik et al., 2018a).

The paper aims to solve the research problem by designing a model of business failure identification. This model is constructed using logistic regression that is one of the most used approaches in this field. During the creation of the best possible Logit model, significant financial and non-financial indicators were identified.

The main contribution of the paper is modelling of business failure of V4 Group companies one year in advance. For model creation, real data of more than 173 000 V4 group companies was used. Therefore, it can be expected that the model has a good representation of the actual specifications of these economics. There is a potential of this model to become a commonly used tool for the prediction of the business failure of companies. The model presented in the paper has a high predictive ability.

The originality of the article lies in the identification of significant determinants in actual post-crisis conditions of the economics in the targeted countries. The model is constructed without regard to any economic sector and any company size. Thus, potential financial risks threatening all companies can be predicted using this model. It can be useful for eliminating potential losses of companies or their stakeholders.

The paper consists of four main parts. The first part presents the literature review, which focuses on the development in the field of business failure prediction models, especially in the economics of the Visegrad Four countries. The section on research methods gives a brief description of data on Polish, Slovak, Czech and Hungarian companies. This section also specifies the principle of logistic regression. The section regarding the results of the research focuses on the description of the created model. Next, based on the analysis of the classification table and the AUC value, the results are discussed and compared, also presenting the analysis of the prediction ability of the model with some prediction models developed in V4 countries.

1. Literature review

Since the first prediction model, developed by Fitzpatrick (1932), researchers created many business failure prediction models, e.g., Altman model (1968), Springate (1978), Ohlson model (1980), Zmijewski model (1984), etc. Based on the reviews of existing models (Kumar and Ravi, 2007; Prusak, 2018; Alaka et al., 2018), two groups of popular tools exist in this field, i.e. statistical tools (multiple discriminant analysis (MDA) and logistic regression (LR) or Logit) and artificial intelligence tools (decision trees, neural networks, etc.). The Ohlson model (1980) was the first prediction model created by logistic regression. Ohlson created a model by using the sample of 105 failed and 2 058 healthy firms. Ohlson concludes that the Logit-based model is more useful as MDA-based models (Waqas and Md-Rus, 2018; Bandyopadhyay, 2006; Shumway, 2001; Jones et al., 2016).

In the Czech Republic, the first attempt at developing a national business failure model was made by Neumaierova and Neumaier in 1995, which resulted in the so-called IN95 model (Neumaierova and Neumaier, 2002). In the following years, the same authors built other national models, namely, IN99, IN01 and IN05 using a larger sample of companies. Jakubík and Teplý (2011) developed the first Czech Logit-based business failure prediction model. As the next step, the authors proposed the aggregation of variables identified using this model. On this basis, they established a so-called JT index. This index was aimed at evaluating the financial health of Czech companies operating in the non-financial sector. However, it has been commonly used by companies of all sectors of the Czech economics. Kalouda (2013) proposed another national bankruptcy prediction model. This model comprises key variables from each of the five key models widely discussed in the literature. It also adds a new variable that proxies for the degree of risk diversification within a company. Karas and Režňáková also published the studies on business failure prediction of Czech companies. They built models using linear MDA and the boosted tree method (Režňáková and Karas 2014; Karas and Režňáková 2013, 2014). Using logistic regression, Vochozka et al. (2015) built a highly efficient model for transportation and shipping companies. Of course, many other Czech national models have been developed, e.g., Čámská (2016), Rybárová et al. (2016), etc.

Hajdu and Virág (2001) developed the first models for business failure prediction in Hungarian companies. The authors used a sample of 154 companies, half of which were insolvent. The models used MDA and LR approaches. Based on the same data, Virág and Kristóf (2005) built a model using artificial neural networks. This model was characterised by higher efficiency compared to previous models. Again, using the same dataset, Virág and Nyitrai (2014) built models using the techniques of support vector machines and the rough set theory. Ékes and Koloszár (2014) estimated models for predicting bankruptcy of Hungarian small and medium-sized companies (SMEs). They used linear discriminant analysis, logit analysis, classification trees, and artificial neural networks. These models were highly efficient, mainly compared to other Hungarian or foreign (Altman, Springate, Ohlson, Zmijewski) models. In 2016, based on data of 1996–2014, Bauer and Endrész (2016) built a probit model for predicting the insolvency of Hungarian companies. In the model, the authors included some macroeconomic variables and qualitative characteristics of companies.

In Poland, the pioneering studies aimed at using foreign models to predict financial distress of Polish companies (Mączyńska, 1994). After that, Gajdka and Stos (1996), Hadasik (1998), Hołda (2001), Hamrol et al. (2004), etc. developed the first Polish national business failure prediction models. Authors created these models based on MDA. Later, the Logit method and some other data-mining methods have been used in many studies presenting Polish national models developed by Gruszczyński (2003), Pisula et al. (2013), Pociecha et al. (2014), Pisula et al. (2015), Brożyna et al. (2016, pp. 93-114). Several studies provide an overview and comparison of existing prediction models (Pawelek et al., 2017; Prusak, 2018; Tokarski, 2018; Wyrobek and Kluza, 2018, Pociecha et al., 2018, Durica et al., 2019).

In Slovakia, the first national models were created using the MDA approach. Gurčík (2002) and Chrastinová (1998) designed models for agricultural companies, but these models were still used to predict the financial difficulties of Slovak companies in various industries. Hurtošová (2009) and Gulka (2016) introduced Slovak Logit models. Kovacova and Kliestik (2017) developed models for bankruptcy prediction of Slovak companies using logit and probit methods and provided the comparison of the overall predictive ability of the developed models. Using the decision tree technique, Karas and Režňáková (2017) and Gavurová et al. (2017) developed a prediction model for companies operating under the conditions of the Slovak economy. Mihalovič (2016) published models for Slovak companies; the first model used an MDA approach and the second — an LR technique.

2. Research methods

In this study, to construct a business failure prediction model, logistic regression was used. It is an appropriate statistical method if the dependent variable is categorical (usually, binary). Independent variables can be categorical and continuous. Logistic regression is useful in similar situations as discriminant analysis. However, this method has the advantage related to input assumptions that are less restrictive. It does not require the assumptions of normality of variables or homoskedasticity of individual groups. The classification capability of the logistic regression model tends to be better than in the case of the model obtained from the discriminant analysis. The prediction models created by various artificial intelligence tools usually achieve a slightly higher predictive ability. However, these are mostly so-called black boxes, and, therefore, these models are complicated to interpret. Therefore, these models are not commonly used in practice for business failure prediction (Alaka et al., 2018).

In logistic regression, all independent variables should be linear and independent of each other. Strongly linear relations, i.e. a high degree of multicollinearity among explanatory variables, could affect the stability of the model. Thus, stepwise regression is used to eliminate this risk and select statistically significant variables (Kliestik et al., 2018a).

The data for the study obtained from the database Amadeus — a database of comparable financial information for public and private companies across Europe covering the years 2016 and 2017. The original database consists of real data on almost 450 000 companies. After deleting incomplete data, the final dataset consisted of data on 173 546 companies.

Similarly, as in Agrawal and Maheshwari (2016), one half of the data was the group of 86 773 non-prosperous companies and the second half was the group of 86 773 prosperous companies. The selection of prosperous companies was made randomly, while no specifics (economic sector, size, and legal form) were considered. Tab. 1 illustrates the division of companies in all considered countries.

The company was included in the non-prosperous sample if its indicators for 2017 satisfied the fol-

Tab. 1. Frequencies of prosperous and non-prosperous companies in V4 countries

Prosperous	Czech Republic	Hungary	Poland	Slovakia	Total
Yes	12 423	51 279	6 595	16 476	86 773
No	12 736	46 923	2 698	24 416	86 773
Total	25 159	98 202	9 293	40 892	173 546

Tab. 2. Financial ratios used as potential explanatory variables

ID	Method for calculation	ID	Method for calculation
X1	Sales / Total Assets	X20	Net Income / Sales
X2	Current Assets / Current Liabilities	X21	Non-current Liabilities / Total Assets
X3	Gross Profit / Total Assets	X22	Cash / Current Liabilities
X4	Net Income / Equity	X23	Cash-flow / Current Liabilities
X5	EBITDA / Sales	X24	Working Capital / Sales
X6	Liabilities / EBITDA	X25	Current ratio
X7	Net Income/ Total Assets	X26	Liquidity ratio
X8	Working Capital / Total Assets	X27	Return on Assets
X9	Operating Profit / Total Assets	X28	Return on Equity
X10	Total Liabilities / Total Assets	X29	Shareholder Liquidity Ratio
X11	Current Assets / Total assets	X30	Solvency ratio (Liability based)
X12	Cash / Total Assets	X31	Cash-flow / Operating Revenue
X13	Cash-flow / Total Assets	X32	Net Assets Turnover
X14	Cash-flow / Total Liabilities	X33	Interest Paid
X15	Current Liabilities / Total Assets	X34	Gross Margin
X16	Current Assets / Sales	X35	Profit Margin
X17	Operating Profit / Interest Paid	X36	Net Current Assets
X18	Stock / Sales	X37	Working Capital
X19	Cash-flow / Sales		

lowing three conditions: (1) the index of the creditworthiness of the company was less than 0.06; (2) the non-prosperous companies were indebted so that the value of liabilities exceeded the value of assets, which meant it had negative equity; and (3) had negative profits after taxes. The inability of a business to generate profits may lead to insolvency (Kliestik, 2018b).

For this study, the values of 37 financial ratios for 2016 served as a basis for the construction of the business failure prediction model (Tab. 2). The indicator of the company size and the indicator of the country, in which the company operated were categorical variables. Therefore, they had to be transformed into dummies. The company size variable *(size)* had three possible values: small, medium, large and very large. Therefore, it is encoded by two dummies *size_Small,size_Large/Very Large*. Medium-sized companies were considered a reference category. Similarly, Slovak companies were considered a reference and companies from the other three countries were encoded by three dummy variables *country_Czech Republic, country_Hungary*, and *country_Poland*. These dummies, together with the ratios mentioned above, represent the initial set of explanatory variables.

Logistic regression was used to classify the observations (companies) into one of the predetermined groups identified by the dependent variable that could usually obtain only two values. In this study, this dependent variable was *Prosperity*, representing the non-prosperous companies, denoted by 1, and prosperous companies denoted by 0. The goal of the logistic regression was to model and quantify the relationship between the individual characteristics (explanatory variables) and the probability of business failure (or the probability of default).

Fundamentals of logistic regression were used according to Hosmer & Lemeshow (2000). The principle was given by the logit transformation of the probability of business failure

$$p = P(Prosperity = 1):$$

$$logit(p) = \ln \frac{p}{1-p} = \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k \quad (1)$$

$\beta_0, \beta_1, \ldots, \beta_k$ — coefficients estimated from the dataset of companies by maximising the log-likelihood function. Then, the probability of business failure was determined by:

$$p = \frac{1}{1+\exp(-\beta_0 - \beta_1 X_1 - \cdots - \beta_k X_k)} \quad (2)$$

Based on this probability, the company was classified as prosperous or non-prosperous, using a cut-off score (usually 0.5), attempting to minimise the Type I error and the Type II error. The Type I error occurred if the non-prosperous company was classified as prosperous, and the Type II error occurred if the prosperous company was classified as non-prosperous. Frequencies of these errors together with frequencies of correct classification formed the classification table (Kliestik et al., 2018a).

After the logistic model was fitted, testing of its statistical significance could be performed. Usually, the likelihood ratio test is used for this purpose. The non-significance of the model was the null hypothesis of this test. For the assessment of the model quality, various R Square statistics (Nagelkerke R Square, Cox and Snell R Square) were proposed. In this sense, the likelihood statistic L and its modifications: $-2lnL$, and the likelihood ratio G^2 should be used (Hu et al., 2006).

Significance of explanatory variables and related coefficients was provided by the Wald test with the test statistic

$$z_{Wald} = \frac{b_i}{s_{b_i}} \quad (3)$$

where b_i — the estimate of the regression parameter β_i and s_{bi} — the standard deviation of this estimate. Using this statistic, the null hypothesis, stating that the coefficient equals 0, was tested. Wald statistic and the Likelihood ratio could also be used to stepwise selection of the significant coefficients and the selection of explanatory variables with a significant impact on the probability of failure (Bewick et al., 2005).

The classification ability of the created logistic regression model was assessed based on the classification table described before. The classification table was used to compare and group the observed and predicted classifications into the categories of prosperous and non-prosperous companies. The table states the absolute and relative frequencies of correctly and incorrectly classified companies as well as the overall classification ability of the model, expressed as the total ratio of the correctly classified enterprises. The company was included in the non-prosperous category if the probability of failure predicted by the model was higher or equal to 0.5; otherwise, it was included in the prosperous group.

Also, the classification accuracy of the created model could be assessed based on the ROC curve (Receiver Operating Characteristic curve). The ROC curve gives an image of the behaviour of the established model, regardless of the division of companies into individual groups and regardless of the weight of particular types of incorrect classifications of companies. The vertical axis shows the percentage of non-prosperous companies that were classified correctly in the non-prosperous group, called a true-positive rate or sensitivity. The horizontal axis shows the percentage of prosperous enterprises that were classified incorrectly in the non-prosperous group, called a false-positive rate or 1-specificity (Fawcett, 2006).

The AUC (Area Under Curve) is a frequently used criterion to compare logistic regression models or to assess the classification ability of the created model. The maximum value of AUC is 1, i.e. 100%. Thus, if the size of the AUC is close to 1, then the created model has an excellent classification ability. If the size of the AUC is close to 0.5, the classification ability of the model is not good.

3. Research results

During the research process, a logistic regression model was designed. This model was created to predict the threat of business failure for one year in advance. Therefore, the dependent variable Prosperity in 2017 and the values of the explanatory variables of 2016 were considered to ensure the correctness of calculations, verification of real data and predictive ability of the model. For the selection of significant explanatory variables, the stepwise forward selection was used, which was based on the Likelihood ratio. Variables *size* (small, medium and large/very large) and *country* (Czech Republic, Hungary, Poland, and Slovakia) had to be expressed as dummy variables.

The final model was created in 17 steps, so it contains 17 statistically significant explanatory variables and a constant. For the sake of clarity, only the output characteristics of the final model are illustrated. The Likelihood ratio test checked the significance of the model (Tab. 3). Based on the significance, the null hypothesis (the model was not significant) was rejected. Also, the results confirmed the significant contribution of the last ranked variable *(X18).* As the explanatory variables significantly differentiate the probability of failure, the model can be considered significant.

Tab. 3. Likelihood ratio test results

	Chi-square	df	Sig.
Step	3 412.372	1	0.000
Model	114 093.97	17	0.000

Tab. 4. R Square characteristics

-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
126 491.871	0.482	0.642

According to value 0.642 of Nagelkerke R Square characteristic (Tab. 4), the model explains more than 64% of the variability of the logit of business failure probability, which is a rather good value.

Tab. 5 provides an overview of the explanatory variables included in the model, the estimated coefficients related to these variables and the results of the testing of their statistical significance. Only significant variables were included in the model, confirmed by the Sig. column, as the stepwise regression method was used.

We can interpret the logistic coefficients b_i (column B) as a change in the value of logit concerning the unit change of the value of the explanatory variable X_i provided that values of all other variables stay constant, however, this interpretation is not practical. More practical is the interpretation of coefficients e^{b_i} (Exp(B)). The value of e^{b_i} means the number of times when the odds that a company will be non-prosperous changes if the value of the corresponding independent variable changes by a unit and values of other independent variables remain unchanged. If $e^{b_i} > 1$, the odds increase, if $e^{b_i} < 1$, the odds decrease. For example, as the value of *X01* (Sales to Total Assets) increases by one, the odds that the company will be non-prosperous, will change 1.03 times. Therefore, the odds are 3% higher. And vice versa, a value of 0.04 for X08 means that an increase in the value of *X08* by one will cause a fall to 4% of the original odds that the company will be non-prosperous.

Only 12 out of all 37 financial ratios selected as potential predictors (Tab. 1) have a significant impact on probability (or odds) of business failure. For variables *X01* (Sales to Total Assets), *X10* (Total Liabilities to Total Assets), *X18* (Stock to Sales) and *X21* (Non-current Liabilities to Total Assets), with the increase in the value of these variables, the odds and the probability of failure also increase. On the other hand, the variables *X08* (Working Capital to Total Assets), *X12*

Tab. 5. Description of the developed model

Variable	B	S.E.	Wald	df	Sig.	ExpB
country_czech republic	-0.138	0.021	42.575	1	0.000	0.871
country_hungary	-0.877	0.029	897.959	1	0.000	0.416
country_poland	-0.599	0.037	258.852	1	0.000	0.550
size_small	1.180	0.023	2 562.388	1	0.000	3.255
size_large/very large	-0.863	0.072	144.810	1	0.000	0.422
X01	0.030	0.002	371.659	1	0.000	1.030
X08	-3.089	0.034	8 291.102	1	0.000	0.046
X10	0.025	0.001	311.124	1	0.000	1.025
X12	-0.002	0.002	1911.917	1	0.000	0.998
X21	0.026	0.004	54.627	1	0.000	1.026
X25	-0.017	0.001	159.794	1	0.000	0.983
X26	-0.091	0.003	996.945	1	0.000	0.913
X27	-1.057	0.037	819.376	1	0.000	0.348
X28	-0.966	0.016	3 641.542	1	0.000	0.381
X35	-1.328	0.038	1 202.718	1	0.000	0.265
X37	-0.001	0.001	1 093.151	1	0.000	0.999
X18	0.042	0.002	630.457	1	0.000	1.043
constant	0.107	0.025	18.568	1	0.000	1.113

(Cash to Total Assets), *X25* (Current ratio), *X26* (Liquidity ratio), *X27* (Return on Assets), *X28* (Return on Equity), *X35* (Profit Margin) and *X37* (Working Capital) have a negative impact on the odds of business failure.

Of course, this interpretation is a little different for continuous explanatory variables (in our case, financial ratios) and dummy variables related to categorical explanatory variables *(country and size)*. For example, in the case of the variable *country*, Slovakia was considered as a reference category. Odds that a company will be non-prosperous were smaller for companies in all remaining V4 countries. Compared to Slovak companies, companies in Hungary and Poland only had a half of all odds to be non-prosperous, and companies in the Czech Republic had the odds that were 13% lower. Of course, other company characteristics must be identical.

The probability (odds) of business failure is significantly affected by the size of the companies. Small companies have more than three times higher odds of being non-prosperous compared to medium-sized companies. On the other hand, large and very large companies have only less than half of the odds to be non-prosperous.

The resulting model expresses the logit of the probability of business failure in the form of a linear combination of explanatory variables (column Variable in Tab. 5) with corresponding regression coefficients (column B in Table 5). Using the reverse transformation of logit to probability, we can estimate the probability of business failure by

$$p = \frac{1}{1+\exp(-Z)} \tag{4}$$

where

Z = 0,107—0,138 · country_Czech Republic—
— 0,877 · country_Hungary—0,599 · country_Poland+
+1,180 · size_Small—0,863 · size_Large,Very Large +
+0,030 · X01 — 3,089 · X08 + 0,025 · X10—0,002 ·
· X12 + 0,042 · X18 + 0,026 · X21—0,017 · X25 —
—0,091 · X26—1,057 · X27—0,966 · X28—1,328·X35—
—0,001·X37.

As usual, 0.5 was considered a cut-off point, which meant that if the business failure probability was higher than 0.5, the company was identified as non-prosperous.

To evaluate the overall accuracy of the estimated model, the classification table (Tab. 6), ROC and AUC were employed. The overall classification ability of our model was more than 88%. This ability was achieved for both prosperous and non-prosperous companies. Thus, the model classifies equally in both groups of companies.

Tab. 6. Classification table

Yes		Predicted Prosperity		Percentage Correct
		No		
Observed Prosperity	Yes	76,606	10,167	88.3
	No	10,454	76,319	88.0
		Overall Percentage		88.1

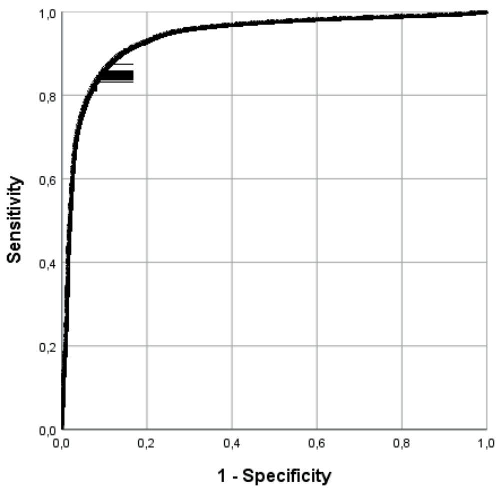

Fig. 1. ROC curve

4. Discussion of the results

In the paper, the logistic regression analysis was used to evaluate the future financial situation companies in V4 countries. The results proved that the selected predictors were acceptable for financial risk measurement and business failure prediction. Using the sample of more than 173 000 companies (86 773 prosperous and 86 773 non-prosperous), a complex prediction model was created with a high overall predictive accuracy of 88.1% (on the test sample). The shape of the ROC curve and the value of AUC (0.939) proved its validation. However, the research has some limitations. The results of the logistic regression analysis may not be perceived as sufficient compared to other methods (e.g. classification trees, artificial neural networks, etc.). It is the objective for further research to reveal, which method is the most appropriate for business failure prediction in V4 countries.

The results indicate that the developed logit model covers the financial ratios of all four basic groups of financial ratios for activity, liquidity, profitability and debt, which confirms the balance of the developed model. There are four activity ratios (sales-to-total-assets ratio, cash-to-total-asset ratio, stock-to-sales ratio and working capital), three profitability ratios (ROE, ROA and profit margin), three liquidity ratios (working-capital-to-total-assets, current and liquidity) and two debt ratios (non-current-liabilities-to-total-assets and total-liabilities-to-total-assets). The coefficient of the working-capital-to-total-asset ratio has the highest impact compared to the other financial ratios in the equation, as it measures the corporate ability to cover its short-term financial obligations. An increasing value of this ratio is usually a positive sign, showing the corporate liquidity improvement over time. Considering the financial ratios of the highest impact in the equation (coefficients more than 1), profit margin and return on equity play an important role. The profit margin ratio shows the percentage of sales left after the business pays all expenses. An extremely low-profit margin indicates the expenses are too high, and the management needs to budget and cut expenses. Return of equity shows how effective corporate management is in generating profit with money the shareholders have invested. The higher the ROE, the more profit a company is making from a specific amount invested, and it reflects its financial health. And vice versa, the more debt a company has, the higher the return on equity ratio.

The importance of the selected financial ratios is underlined by the fact, that the information about the future corporate prosperity eliminates potential financial risks and enables to evaluate the financial health of the company based on selected financial ratios or other characteristics of enterprises or the economic and national environments, in which they operate.

The comparison of the model created in this study with models developed by other authors for the V4 countries demonstrates that it achieves comparable results. Kliestik et al. (2018c) studied business failure prediction in V4 countries using the MDA approach. They formed a prediction model for each V4 country and a complex V4 model based on the same dataset as in the case described in this article. National models achieved higher prediction ability (between 87% and 93%) compared to the V4 model with an overall accuracy of 85.9%. The model presented in this paper outperforms these results.

In 2016, using public data from the accounting statements, Němec and Pavlík (2016) created a Logit-based model for predicting the insolvency risk of the Czech companies with a one-year forecast horizon. The authors used data on 2 061 Czech companies in total (1 022 healthy companies and 1 039 insolvent companies) from 2005 to 2013. Their model works with six financial ratios (from the original 30 ratios) and achieves the overall classification ability of nearly 84%. The model presented in this paper has a better result in this respect.

Brożyna et al. (2016) applied classical linear MDA, LR, classification trees and the method of nearest neighbours for predicting bankruptcy of Polish companies operating in the logistics sector. As predictors, authors used 28 financial indicators of the companies. Their Logit model for predicting bankruptcy for one year in advance achieved a predictive power of 78% for prosperous companies, and 90% of non-prosperous companies, and its AUC was 0.95. The model presented in this paper has a very similar classification ability and AUC. However, the model presented in this paper was created based on a much larger data sample. Thus, it can be assumed that this model provides a better reflection of the conditions particular to the Polish economy. From this point of view, the model presented in this paper can be considered a stronger model.

In 2016, two Slovak national bankruptcy prediction models were published by Mihalovič (2016). The first one was estimated using discriminant analysis, while the second was based on logistic regression. Both models were estimated based on a dataset of real 236 companies operating in Slovakia. The results of this study suggest that the Logit-based model outperforms the classification ability of the discriminant analysis-based model. The final Logit model works with only six financial ratios as predictors. However, the predictive ability of this model is less than 69%, and the AUC value is 0.772. Thus, the model presented in this paper is much more usable in the Slovak economy.

Bauer and Endrész (2016) published a bankruptcy prediction model for Hungarian companies. For the development of this model, the Probit method was used. Authors combined micro- and macro-economic data for 1996–2014. AUC of this model is 86%, and R Square is only about 23%. Even though the authors used a relatively robust sample to fit the model, the model presented in this paper can be considered a better choice.

The mentioned models were created based on national conditions of individual V4 countries. However, mostly, they were created based on older data. The model presented in this paper was based on data for 2016 and 2017. During this period, no significant disturbances in the economies of V4 countries were observed. The consequences of the global crisis have already disappeared, so the dataset used in this study reflects the actual conditions of these economies.

Moreover, except for the model by Bauer and Endrész (2016), the models of other mentioned authors do not consider the size of the companies. The model presented in this paper incorporates the information about the size of the company, which proved to be a significant predictor of the probability of financial difficulties of companies. Due to their size, the economic environment and the financial situation of companies can vary considerably, so this information is considered important in the prediction of bankruptcy.

The model is complex and allows predicting business failure in all V4 countries. It allows for easier management implementation. Probably, if individual national models would be created, they would have higher predictive ability. This hypothesis needs to be tested in further research, to reveal which possibility is the most appropriate. Another future research issue is a potential usage of the created model beyond the V4 countries. Given that the model considers the current economic conditions of V4 countries, the lower predictive ability is expected outside these countries.

The issue of financial risk management reveals many possible ways of coping with the risk that affects the financial aspects of companies. One of them is to predict the future financial situation of the company. The results gained in the research are especially important for companies themselves, but also their business partners, suppliers and creditors to eliminate financial and other corporate risks related to the unhealthy or unfavourable financial situation of the company.

Although many business failure prediction models have been created worldwide, the originality and novelty of the proposed model lie in using the logistic regression method while considering the specific post-crisis economic conditions of V4 countries.

Conclusions

Based on selected financial indicators or other characteristics of the companies, business failure modelling helps to predict their financial challenges. It provides information about future company prosperity and, thus, eliminates potential financial risks.

Using logistic regression, we identified the statistically significant parameters that reflect the future financial development of the company. Thus, a Logit model was designed to predict potential company failure. The predictors that were identified were sufficiently significant to manage financial risks and to predict the failure of companies operating in V4 countries.

The developed model has some limitations. The relatively low value of the Nagelkerke R square (64.2%) means that there is some space for other parameters than can have some impact on corporate prosperity. Also, the choice of the method of logistic regression may not be perceived positively. Despite this, it was possible to identify significant predictors and to achieve a high classification ability of the model.

On the other hand, the results could differ based on the data set. Therefore, the proposed models should be tested in the following years to find out the possibilities for the construction of the business failure prediction model generally accepted considering the economic conditions of V4 countries.

Acknowledgement

This research was financially supported by the Slovak Research and Development Agency, Grant NO. APVV-14-0841: Comprehensive Prediction Model of the Financial Health of Slovak Companies, and the Faculty of Operation and Economics of Transport and Communications, University of Zilina, Slovakia, Institutional Grant No. 11/PEDAS/2019: Using selected data mining methods in business failure prediction.

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Volume 11 • Issue 4 • 2019

Engineering Management in Production and Services

sciendo

International Society for Manufacturing, Service and Management Engineering

received: 15 June 2019
accepted: 15 October 2019

pages: 65-79

Logistics decision-making based on the maturity assessment of imperfect knowledge

Lech Bukowski

ABSTRACT

The main purpose of this article is to develop a method that allows for an objective quality assessment of imperfect knowledge, which is necessary for decision-making in logistics. The methodology aimed at achieving this goal is established on the system analysis of the entire process employed for obtaining, processing and using data and information as well as the knowledge generated on this basis. The result of this work is a general framework that can be used for managerial decision-making in smart systems that are part of Industry 4.0, and, in particular, Logistics 4.0. A key theoretical contribution of this framework is the concept for quantitative assessment of the maturity of imperfect knowledge acquired from Big Data. The practical implication of this concept is the possibility to use the framework for the assessment of the acceptable risk associated with a managerial decision. For this purpose, the article presents a brief example of how to use this methodology in the risk-taking decision-making process. Finally, the summary and discussion of the results are offered.

KEY WORDS

Industry 4.0, Logistics 4.0, Big Data, imperfect knowledge, knowledge maturity

DOI: 10.2478/emj-2019-0034

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Introduction

The contemporary networked world, characterised by the Internet of Things and Services, is leading to the emergence of smart grids in the field of energy supply, sustainable mobility strategies, such as smart mobility and smart logistics, and smart health in the realm of healthcare (Kagermann, Wahlster and Helbig, 2013). In the area of manufacturing, this trend led to the fourth stage of industrialisation — Industry 4.0, which focuses on creating smart products, procedures and processes. Smart factories are capable of managing complexity, are less susceptible to disruptions and able to manufacture goods more effectively and efficiently. In this environment, human beings, machines and resources communicate with each other in the same way as in a social network. Its interfaces with smart mobility, smart logistics and smart grids will make the smart factory a key component of tomorrow's smart infrastructures. This drives forward the transformation of conventional value chains and the emergence of new business models. A comprehensive literature analysis of the problems related to the challenges of the so-called the fourth industrial revolution is already discussed in the publication by Ślusarczyk et al. (Ślusarczyk, Haseeb and Hussain, 2019) and will not be duplicated here.

The implementation of Industrie 4.0 requires an interdisciplinary approach and close cooperation with other key areas. Consequently, logistics plays a key role in the mutual coordination of individual processes implemented under these systems. Fig. 1 presents a simplified interrelationship between individual subsystems that compose the "system of systems" of Industry 4.0 (Bukowski, 2016a). Also, it illustrates the symbolic role of logistics management as Logistics 4.0. As the diagram suggests, smart equipment, which is operated using robots and sensors, as well as smart information and communication technologies (ICT based on Big Data and Cloud Computing) are of fundamental importance for the effective implementation of processes under Industry 4.0 and Logistics 4.0. The quality of knowledge acquired from ICT has a particularly significant impact on making the right decisions within these systems. Therefore, an important issue is to develop a method that allows objective quality assessment of the entire process used to obtain and process data and information as well as the knowledge generated on this basis.

The purpose of this article is to develop a method that allows for such an assessment based on the analysis of knowledge creation and decision-making using expert methods. The work is organised as follows: first, the evolution of the concept and the scope of logistics is characterised, followed by specific features of Logistics 4.0, and, on this basis, a new method for assessing knowledge maturity is proposed. Next, a brief example is presented, depicting the use of this method in the risk-taking decision-making process. Finally, the results are summarised and discussed.

1. Logistics evolution — from Logistics 1.0 to Logistics 4.0

The modern concept of "logistics" was shaped in the military field in the first half of the 19th century and included transport, accommodation and supply of military units, as well as transport, storage and supervision of goods intended for the army (Blaik, 2010; Michlowicz, 2002). In the 1950s, this concept of logistics started being transferred from the sphere of national defence to business. The term "business logistics" emerged, which included transport, warehousing and transshipment processes of goods within one enterprise and between different enterprises (Schönsleben, 1998; Stock and Lambert, 2001).

The turning point in the development of modern logistics was the publication of the article "Note on the Formulation of the Theory of Logistics" by Morgenstern in 1955 (Morgenstern, 1955). In the Ger-

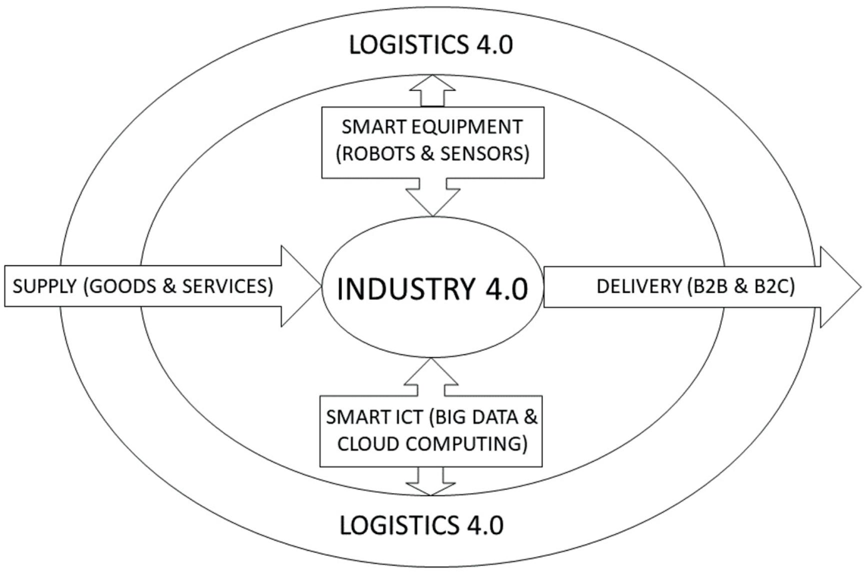


Fig. 1. ROC curve

man-speaking area, the year 1973 is regarded as the date of the birth of civil logistics, which is the year of issue of the book "Business logistics — systems, decisions, methods" (Kirsch et al., 1973). The authors of this book understood logistics as "... shaping, controlling, regulating and implementing energy, information and people flows, in particular materials and products, within a given system and between systems …". In the next years, the interest in practical aspects of logistics has grown significantly in Europe, which resulted in the creation of a practical definition of logistics in the form of the so-called 7R rules (from the English word "right" or from the German "richtig"). The interpretation of this rule means that the basic task of logistics is to provide the right goods, in the right quantity, at the right time, to the right place, with the right quality, at the right costs along with the right information (Lasch, 2014).

At the end of the 1980s, the representative of the German logistics school Reinhard Jünemann generalised this definition, proposing to understand logistics as "... a scientific field of knowledge including planning, control and checking of material, energy and information flows within systems" (Jünemann, 1989). Such understanding of the logistics concept has opened new perspectives for scientists dealing with logistic issues, creating opportunities for the search of theoretical models in the broadly understood area of logistics knowledge. The individual phases and directions of civil logistics development since its foundation to the current state have been described and analysed in detail by many authors (e.g. Pfohl, 1998; Witkowski, 2010; Lasch, 2014; Bukowski, 2019). On this basis, the development of logistics in business can be divided into four stages, whose brief characteristics are presented in Tab. 1.

Logistics 1.0 covered the sixties and seventies of the twentieth century and was characterised by marketing orientation. The main task of logistics was defined as "providing raw materials, semi-finished products and finished products in accordance with the principle of 7R". The dominant approach at this stage of logistics development was functionally targeted, which means that the optimisation of logistic operations was seen as a part of separate functions and not as a part of the whole delivery process. This orientation often resulted in problems at the interface of individual functional areas (e.g. bottlenecks in flows and weak links in systems) and hindered the comprehensive optimisation of entire logistics processes (Coyle et al., 2010; Krawczyk, 2011).

In the eighties of the twentieth century, a new concept — Logistics 2.0 — was introduced. It emphasised the coordinating role of logistics in managing the flows of all goods between the place of their origin (e.g. by a producer) and the destination (e.g. a recipient). It was connected with an increase in the complexity of logistics systems and the dynamic development of the new role of logistics, namely, the organisation of returns of used materials, goods and packaging (reverse logistics). The functional approach gradually gave way to a regulatory approach, in which management decisions were usually reactions to changes taking place over time. The function of the logistic objective was subordinated to the idea of "lean thinking", which concerned the manufacturing (lean manufacturing), organisational and management (lean structures and lean management) areas. The next phase of Logistics 2.0, at the turn of the 1980s and 1990s, was largely a response to significant market changes, namely, limiting mass production, allowing the full use of economies of scale for flexible adaptation to the needs of the unpredictable customer (logistics systems and processes, regardless of the ownership structure of individual parts of the supply chain, and the economy of scope instead of the economy of scale). Such a change in the functioning of the industry required the use of a new dynamic approach, considering the environmental variability in time. The predominant problem in this phase was the conflict between the struggle for full flexibility while adapting to the changing market requirements (responsiveness) and rising costs (Harrison and van Hoek, 2009).

The next step — Logistics 3.0 — can be characterised by the concept of the supply chain as a sequence of processes related to the flow of goods across the borders of individual organisations, ranging from the acquisition of raw materials to the final user of goods (E2E concept). Such a change in perspective related to logistics issues enabled a comprehensive approach to the optimisation of transition from flexibility in supply management to its higher level, i.e. agility. The integration of logistic systems and processes became the foundation for further stages of modern logistics development (Blanchard, 2015).

The fourth stage — Logistics 4.0 — started with the beginning of the 21st century and was driven by the ever-expanding economic globalisation. Optimisation methods based on the concept of Porter's value creation chain to improve the efficiency of logistics

Tab. 1. Development steps of logistics in business practice

Stage	The main characteristic	The dominant approach	The main goal
Logistics 1.0	Delivery of goods in three steps: “transport — transshipment — storage”	functional, regulatory, reactive	effectiveness
Logistics 2.0	Management of goods flow processes within a single enterprise	systemic, active	lean, flexibility
Logistics 3.0	Comprehensive management of the goods flow in supply chains	integration across the borders of the organisation	efficiency, agility
Logistics 4.0	Optimisation and virtualisation of logistics networks within the 3rd IT platform (SMAC)	dynamic, global perspective, real-time operation (RTE)	effectiveness efficiency, leagility, resilience

systems and a dynamic approach in modelling and simulation of logistics processes have been used on a larger scale (Blaik and Matwiejczuk, 2008). At the same time, the virtualisation of logistics networks occurred within the so-called third IT platform, which is often described by the acronym SMAC (Social, Mobile, Analytics, Cloud). This trend, commonly known as e-logistics or smart logistics (Adamczewski, 2016), fully fits in the currently developed model of the so-called economics of the moment (also known as “now economy”), and implemented mostly in the real-time organisations (RTE — Real-Time Enterprise). The goals of modern logistic systems are multiple, namely, effectiveness, economic efficiency, leanness and, at the same time, agility (so-called “leagility”) and resilience to disruptions (Gudehus and Kotzab, 2009).

In practice, Logistics 4.0 was created as an integral part of the Industry 4.0 concept (Kagermann et al., 2013; Wieland, Handfield and Durach, 2016). The dynamic development of manufacturing according to the concept of Industry 4.0 is a result of such processes as globalisation, IT development (e.g. Internet of Things) and international cooperation. To complete these tasks, the production must be supported with modern logistics, i.e. Logistics 4.0. Therefore, the next section will discuss the most important features of Logistics 4.0 that distinguish it from earlier versions of logistics.

2. Main characteristics of Logistics 4.0

The origins of Logistics 4.0 is the concept of the fourth industrial revolution defined usually by machine-to-machine communication and autonomous processes (Strandhagen et al., 2017). This section will try to answer the following question: what are the distinct characteristics that define the logic behind Logistics 4.0? Five most important features that characterise the modern version of Logistics 4.0 age given below.

2.1. Full integration with Industry 4.0

One of the most important facets of Logistics 4.0 is its ability to integrate seamlessly with Industry 4.0 systems, creating a symbiotic, synergistic relationship between producers and delivery services. To achieve the optimal relationship between logistics and smart manufacturing, it is necessary to share data and IT resources between logistics operations and manufacturing companies. This will allow the entire supply chain to provide better efficiency and effectiveness, so that global supply chains will be leaner, smarter, and more agile as a whole, cohesive, interconnected system (Ślusarczyk, Haseeb and Hussain, 2019).

2.2. Implementation of Internet of Things

The adoption of Internet of Things (IoT) both enables and enhances such technology as smart systems, by connecting them (usually via the cloud) to a company’s existing IT systems. For instance, some companies have deployed heat and light sensors in their storage areas to prevent the possibility that a particular product might become damaged or destroyed by poor physical conditions. If the sensors determine that this damage is likely to have occurred, they can send alerts back to inventory managers and production planners to ensure that existing production and transport plans are adapted to the changing situation (Tadejko, 2015).

2.3. Using smart systems and solutions

Smart versions of traditional logistics systems and components are changing the way that goods move from suppliers to customers. Smart containers and smart pallets, for example, are transforming traditional shipping workflows into new opportunities to collect and act on crucial information about whatever stock is being moved. A smart pallet could alert users if it were being filled more than its maximum weight capacity, to prevent wear and tear or increasing load-time efficacy. In the future, this will allow increasing autonomous decision-making in the supply chain compared to the level of autonomous decision-making currently being seen in advanced Industry 4.0 environments. Usually, this is associated with an increase in the number of driverless cars and trucks. This trend will likely begin on a smaller scale, e.g. with robots that can make inventory restocking decisions on their own, saving time and money (Wieland, Handfield and Durach, 2016).

2.4. Visibility across the entire supply chain

One of the most crucial aspects of modern logistics is the increase in visibility that comes from enhanced digitisation across the entire supply chain (E2E). Usually, increased visibility is the first step to building a smarter value stream as well as a necessary prerequisite to the kind of transparency and intra-operational collaboration. That helps make modern logistics much more efficient and comprehensive compared to its earlier manifestations, especially by creating additional planning stability. Smart ports like in Abu Dhabi are already implementing solutions that make possible real-time viewing of documents and other mission-critical information for freight forwarders and their customers (Wieland, Handfield and Durach, 2016).

2.5. Big Data Analytics

In recent years, a lot has been done in the area of collecting huge amounts of data (so-called Big Data) in new logistics frameworks, but the real value of that data is not limited to making manual planning efforts more cohesive. The advances in transparency, visibility and data collection using sensors and RFID chips is a result of the utilisation of analytics processes. By feeding large quantities of data and information into predictive and prescriptive algorithms, logistics providers can improve their demand and supply forecasts while uncovering potential areas of waste or possible improvement activities in their value streams. This can help in the development of a smarter version of supply chain management, that is less susceptible to risk, disruptions, and opacity; however, it is also paving the way for the rise of anticipatory logistics, which predict and act on customer needs before they arise (Bukowski, 2019).

As this short review of the most important characteristics of Logistics 4.0 suggests, the basic condition for its introduction is access to advanced and reliable ICT systems. These systems are based, at present, on intangible assets in the form of Big Data. Therefore, the next part of the work will concern the provision and management of knowledge based on Big Data veracity as a prerequisite for the functioning of systems based on the Logistics 4.0 concept.

3. Assessing knowledge maturity — a general framework based on the concept of imperfect knowledge

In the second half of the twentieth century, a model of "the pyramid of knowledge hierarchy" was created by Ackoff. This model became the foundation of a dynamically developing concept of knowledge management, and it has undergone a number of interpretative modifications. The pyramid of knowledge is based on data that usually occur in the form of symbols and represent individual observations of real-world states. Data represent raw facts, events, or statements without reference to other things. It does not have a meaning in itself. Usually, data is understood as atomistic tiny packets that have no inherent structure. Data can be measurable or not, analogue or discrete, as well as considered statically (e.g. data record) or dynamically (e.g. data stream). It can be obtained from various sources (Ackoff, 1989).

Information is data that are processed to be useful, and it means data that has been given meaning (e.g. relational connection), relevance and purpose. Information is partly subjective because it depends not only on the data but also on the process of their interpretation, which is based on the knowledge held by the knowledge interpreter at that time. Thus, it can be assumed that information is a collection of selected data, processed and presented in a form that can be useful to the recipient (e.g. the decision-maker). The basic condition for the usefulness of information is its ability to be interpreted in a specific context (Skytter, 2008).

Knowledge is created by integrating new information with existing knowledge (so-called background knowledge) about a particular area of interest. It requires the ability to evaluate available information and understand the reality in light of this information, in accordance with the current state of knowledge. Knowledge relies on the ability to use information effectively and efficiently to find answers to more complex questions, such as "how?". Knowledge is emergent in relation to information — it is possible to generate new knowledge by applying processes of systematisation and structuring of information (Klir, 1991).

In 1957, Bergmann published "Philosophy of Science", in which he made a distinction between "perfect" and "imperfect" knowledge. Perfect knowledge is based on complete theories, deterministic nature laws (such as Newtonian mechanics); it concerns closed systems, in which the initial conditions are known accurately, and the only method used in the inference is the deductive method (Bergmann, 1957).

Whereas, in applied sciences, such as engineering, social sciences, economics or management, knowledge is based on incomplete theories and indeterministic laws. It concerns open systems, in which the initial conditions are known inaccurately, and the method used in the inference is usually the inductive method. It is, therefore, imperfect knowledge. The data, on which the entire pyramid is built, come from observations or measurements whose accuracy is limited and, therefore, burdened with errors. If it is possible to repeat the same observations or measurements, the use of statistical methods minimises the impact of these errors on our knowledge. But in many cases, it is not possible, and then, the knowledge has a high degree of uncertainty (Magruk, 2017; Bukowski, 2019).

The problem of knowledge imperfection has become particularly important as a result of the increased use of vast data amounts, called "Big Data" (Corrigan, 2013). For these reasons, one of the key problems in the effective use of smart systems based on data streams, such as Logistics 4.0, is the objective assessment of the reliability of this data and the quality of knowledge based on it (Weerdmeester, Pocaterra and Hefke, 2003). For this purpose, a general framework was developed based on the imperfect knowledge concept, the diagram of which is presented in Fig. 2.

The entire process of knowledge preparation for managerial decision-making can be divided into eight steps, namely: raw data acquisition, data processing to Big Data format, data veracity appraisement, information forming, information utility estimation, creation of new knowledge, knowledge processing quality evaluation and knowledge maturity rating. The basis of the procedure is the idea to combine both quantitative and qualitative methodologies in logistics research (Mangan et al., 2004). Next, the main stages of this process will be discussed in detail.

Big Data includes data sets with sizes beyond the ability of software tools commonly used to capture, manage, and process data within an acceptable period, and can be described by the following characteristics (so-called "10Vs" model):

- Volume represents data size. It refers to the huge amount of data being generated and used in IT systems. The Internet of Things (IoT) is creating exponential growth in data, and what in the past used to be measured in Gigabytes is now measured in Zettabytes or even Yottabytes;
- Velocity is the speed, at which data becomes accessible by a user. It refers both to the increasing rate of data sets and constantly growing demand for access to databases;
- Variety refers to different types of data. It can include many different kinds of data, such as numbers, messages, photos, sensor data, voice or video. It can be structured, semi-structured, and unstructured;
- Variability refers to the changeability of data over time. If the meaning of data is changing in time, it can have a huge impact on data homogenisation;
- Visualisation it the use of charts and graphs to visualise big amounts of complex data. It is far more effective in the communication of meaning than spreadsheets and reports with numbers and formulas;
- Value refers to the benefits that the data can bring to the user;
- Validity refers to how accurate and correct the data is for its intended use;
- Volatility concerns the amount of time, for which the data is useful before it becomes irrelevant;
- Vulnerability refers to how susceptible data is to unauthorised access and how safe it is to use it;
- Veracity refers to truthfulness and reliability of data. Highly complex data sets contain significant

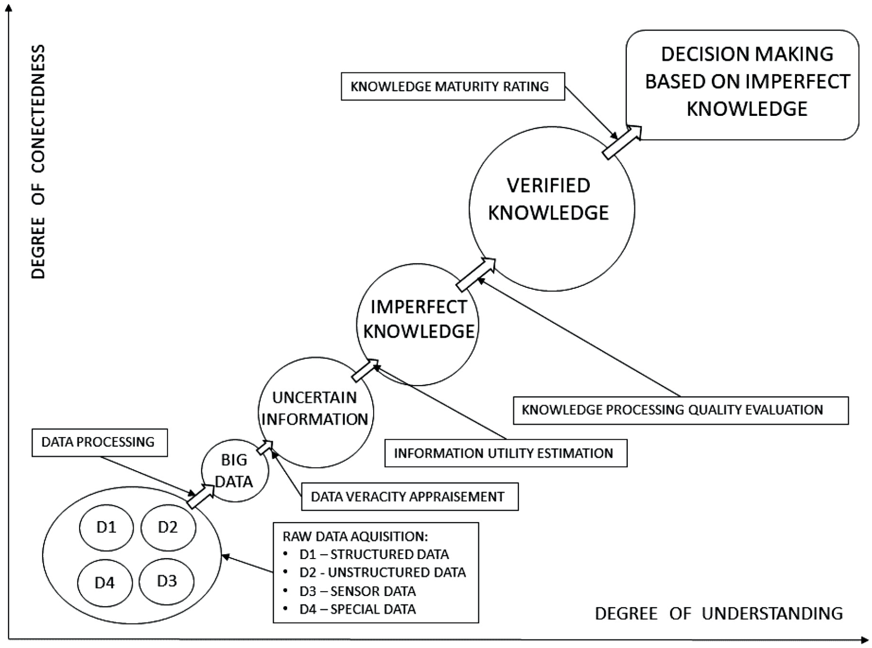


Fig. 2. Diagram of the knowledge preparation process for managerial decision-making

amounts of dubious data (data in doubt), which constitutes database imperfections.

Data veracity has decisive influence on the degree of quality of information. It depends on the imperfection of the data due to (Klir, 1991) incorrectness, incredibility, implausibility, inconsistency, incoherency, vagueness, ambiguity, incompleteness, imprecision and inaccuracy. The proposal is to use the following definition of data veracity based on Bukowski (2016):

Data Veracity (DV) is the property of the data described by the five-dimensional vector of its attributes, namely:

- Accuracy (ACC) — the degree, to which the data fulfil the relevant requirements (the data should precisely meet certain specifications and standards).
- Clarity (CLA) — the degree, to which the data can be clearly understood (the data should be well defined, without several meanings, vagueness and ambiguity).
- Consistency (CON) — the degree, to which the data is compatible with the same type of data from different sources (the data should be coherent without a confusing or conflicting meaning).
- Plausibility (PLA) — the degree, to which the data fits the reality (the data should be compatible with the reality, imaginable and possible).
- Traceability (TRA) — the degree, to which the data can be traced to its sources (the origin of the data should be identifiable with confidence).

This definition can be illustrated by the following relation

$$\mathrm{DV} = \{\mathrm{ACC}, \mathrm{CLA}, \mathrm{CON}, \mathrm{PLA}, \mathrm{TRA}\} \qquad (1)$$

To use this model for the assessment of data veracity, the expert method is proposed. Each veracity attribute Ai is rated on a 3-point scale as:

0 — unacceptable,
1 — acceptable,
2 — fully satisfactory,

and on this basis, the Data Veracity Value (DVV) is calculated as the product of all five attributes A_i.

$$\mathrm{DVV} = \prod_{i=1}^{5} \mathrm{A_i} \qquad (2)$$

The result of the assessment is to assign them to one of five classes, namely:

- Rank 0 — very low (VL), unacceptable,
- Rank 1 to 2 — low (L),
- Rank 4 to 8 — moderate (M),
- Rank 16 — high (H),
- Rank 32 — very high (VH).

Data, for which Data Veracity Value is very low (DVV = 0), should be fully eliminated and must not be used to create information.

Information uncertainty may be due to objective reasons caused by data imperfections and subjective errors caused by errors in their interpretation. In practice, the uncertainty of information is largely determined by the quality of the available data. Thus, their interpretation, and the elimination of false and contradictory data, as well as the clarification of their definitions in the case of data ambiguity, are of great significance in the process of information acquisition. This crucial as the degree of information uncertainty determines its quality and usefulness for creating new knowledge.

The following characteristics of information quality are proposed (Bukowski, 2019):

- Accessibility — the extent, to which information is available, or easily and quickly retrievable;
- Accuracy — the extent, to which data are correct, reliable and free of error;
- Amount of data — the extent, to which the quantity or volume of available data is appropriate.
- Availability — the extent, to which information is physically accessible;
- Believability — the extent, to which information is regarded as true and credible;
- Completeness — the extent, to which information is not missing and is of sufficient breadth and depth for the task at hand;
- Concise — the extent, to which information is compactly represented without being overwhelming (i.e. brief in presentation, yet complete and to the point);
- Consistency — the extent, to which information is presented in the same format and compatible with previous data;
- Efficiency — the extent, to which data are capable to quickly meet the information needs for the task at hand;
- Navigation — the extent, to which data are easily found and linked to;
- Objectivity — the extent, to which information is unbiased, unprejudiced and impartial;
- Relevancy — the extent, to which information is applicable and helpful for the task at hand;
- Reliability — the extent, to which information is correct and reliable;
- Reputation — the extent, to which information is highly regarded in terms of source or content;
- Security — the extent, to which access to information is restricted appropriately to maintain its security;
- Timeliness — the extent, to which the information is sufficiently up-to-date for the task at hand;
- Understandability — the extent, to which data are clear without ambiguity and easily comprehended;
- Usability — the extent, to which information is clear and easily used;
- Usefulness — the extent, to which information is applicable and helpful for the task at hand;
- Value-Added — the extent, to which information is beneficial and provides advantages from its use.

In reality, the quality of information depends on the context, in which it is used. Therefore, in the decision-making process, it is essential to evaluate the usefulness of information in the context of its specific purpose. Based on the literature (Kulikowski, 2014), it is proposed to use the term information utility as an equivalent of the usefulness of information, and the following definition of this term (based on Bukowski, 2019):

Information Utility (IU) is the property of the information described by the five-dimensional vector of its attributes:

- Believability (BEL) — the degree, to which the information can be considered reliable (the information should be believable, credible and from a reputable source);
- Completeness (COM) — the degree, to which the information does not contain omission errors (the information should include all the necessary values, be complete, cover the needs of existing tasks and have a sufficient extent and deepness);
- Correctness (COR) — the degree, to which the information is proper (the information should be free from errors);
- Relevancy (REL) — the degree, to which the information is useful in a given case (the information should be relevant and applicable to the work, as well as appropriate for existing needs);
- Timeliness (TIM) — the degree, to which the information is up to date (the information should be sufficiently timely, current for the work and fresh enough to satisfy needs).

This definition can be exemplified by the model, which represents the following relation

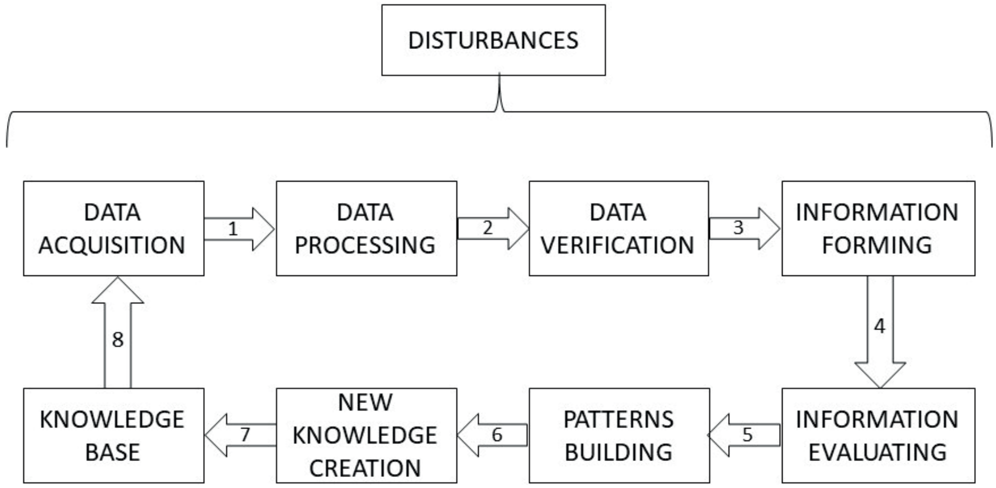
$$\mathrm{IU} = \{\mathrm{BEL}, \mathrm{COM}, \mathrm{COR}, \mathrm{REL}, \mathrm{TIM}\} \tag{3}$$

To use this model to assess the Information Utility, the proposal is to use the following expert method. Each IU attribute Bi is rated by experts on a 3-point scale as:

1 — low,
2 — moderate,
3 — high,

and on this basis, the Information Utility Value (IUV) is calculated as the product of all five attributes B_i.

$$\mathrm{IUV} = \prod_{i=1}^{5} \mathrm{B_i} \tag{4}$$



1 - raw data; 2 - selected data; 3 - verified data; 4 - raw information; 5 - selected information; 6 - structuralized information; 7 - new knowledge; 8 - initial knowledge

Fig. 3. Model of the knowledge-creation process

The result of the assessment is to assign them to one of five classes, namely:

- Rank 1 to 4 — very low (VL),
- Rank 6 to 12 — low (L),
- Rank 16 to 48 — moderate (M),
- Rank 72 to 108 — high (H),
- Rank 162 to 243 — very high (VH).

The imperfection of knowledge is due to the uncertainty of the obtained information and the imperfection of the process of integrating this information with the existing knowledge in the field (Albjoren, and Haldorson, 2002). The general model of the knowledge creation process is shown in Fig. 3. This entire process can be presented as a chain of operations and flows that are subjected to disturbances.

The raw data stored in the "Data Acquisition" block is sent to the "Data Processing" block and subjected to the preparation process. The processed data flow to next block of "Data Verification", where they are verified for their veracity (VER) and then sent to the "Data Forming" block for information to be generated using the procedures of Data Mining and Fusion of Data. Raw information flows to the "Information Evaluating" block, where they are evaluated for their utility value (IUV) and classified on this basis. The selected information is used in next block of "Building Patterns" to seek relationships between individual pieces of information and build logical patterns. On this basis, new knowledge is generated in the "New Knowledge Creation" block. The last stage of the chain is to enrich the existing knowledge base with new knowledge and to create the background knowledge for further acquisition of new data.

Aiming to ensure the quality of information, the process of data processing is of utmost importance; therefore, it will be described in more detail. In this step, four main tasks may be differentiated: data cleaning, data integration, data transformation, and data reduction. The description of typical procedures involved in these tasks is shown below (based on Al Shalabi, Shaaban, and Kasasbeh, 2006).

The data cleaning task involves three main operations, which can be supported by numerical methods:

- the replacement of empty or missing values by calculated numbers using the remaining attribute values,
- the improvement of data accuracy through the replacement of the current value with the newly calculated result or through the removal of the current value;
- the removal of data inconsistency trough specialised procedures (e.g. control codes) programmed in the form of data collection sheets.

Knowledge extraction relies on denoting the data in the form of a two-dimensional table (matrix) because the column-row structure (e.g. a calculation sheet) is the most convenient. At this stage, the main operations are performed with following procedures:

- recognising and identifying attributes, which could not have been identified in the cleaning process;
- removing unnecessary redundancy by comparing the attribute values with the aim of removing the needless data;
- unification of the data from different sets with the same form, for instance, using the same units.

Data transformation includes all the issues connected with transforming the data into a form which makes its exploration possible. This process involves four main operations:

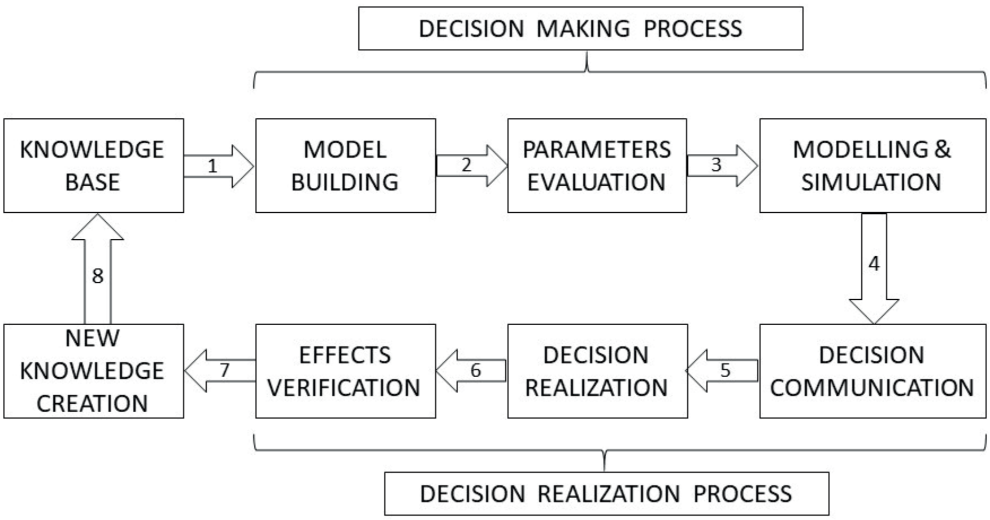
- data smoothing by the elimination of the local deviations having the character of noise. This process involves the techniques, such as regression, binning, or clustering;
- data generalisation by converting the collected data into higher-order quantities (e.g. by their discretisation);
- data normalisation by the adjustment (e.g. rescaling) of the data to a specified range, usually from 0 to 1;
- data accommodation by transforming the data into a new format used by a specific algorithm.

Data reduction consists of the attribute selection with the expert opinion and experience pertaining to the data under analysis. Those attributes that do not have any influence on the modelled features should be removed from the data set. The general aim of the data reduction techniques is to significantly reduce the amount of data. Data reduction stage includes four operations:

- the selection of an attribute by eliminating attributes that are redundant or have little significance for the modelled phenomenon;
- the reduction of the dimension and size by transforming the data and eliminating the recurrence or similar cases;
- data discretisation by transforming a continuous variable into a discontinuous (discrete) and specified number of ranges;
- data aggregation by summing up the most frequent data (e.g. in the function of time).

The generalised model of imperfect knowledge management is shown in Fig. 4. The complete process is presented as a sequence of operations and flows that are subjected to different kind of disturbances. The knowledge stored in the "Knowledge Base" block is sent to the "Model Building" block and forms the basis, on which the exact type of a decision model is selected. The information about the type of the chosen model flows to the "Parameter Evaluation" block, in which parameters of the chosen model are determined, and it is then sent to the next block, namely, "Modelling and Simulation". In this block, suitable investigations are carried out on the chosen parametric model to find the best of all possible decisions, and then, the made decision flows to the "Decision Communication" block. In the next step, the information about the decision flows to the "Decision Realization" block, and after, flows into the "Effects Verification" block. In this block, the results of this decision are tested, conclusions for the future are proposed, and a part of new knowledge in New Knowledge Creation is generated. The last stage of the process is to improve the existing knowledge base with new knowledge and to create the updated initial knowledge for further decision-making.

Based on the above concept, the proposal is to describe the knowledge processing quality (KPQ) by using the five-dimensional vector of its attributes as follows:



1 - knowledge flow; 2- model type; 3 - parametric model; 4 - decisions made; 5 - information flow; 6 - information flow; 7 - information flow; 8 - new knowledge

Fig. 4. Model of the imperfect knowledge management process

- Model Type Adequacy (MTA) — the degree, to which the model reflects the reality with sufficient plausibility and sensibility;
- Model's Parameters Accuracy (MPA) — the degree, to which the model reflects the reality with sufficient precision;
- Decision-Making Process Correctness (DMC) — the degree, to which decisions are made without significant errors;
- Decision Communication Process Reliability (DCR) — the degree, to which the decisions are communicated without faults;
- Decision Realization Process Compliance (DRC) — the degree, to which the decisions are carried out in agreement with the intention of the decision-maker.

This concept can be illustrated by the model, which represents the following formula:

$$\mathrm{KPQ} = \{\mathrm{MTA}, \mathrm{MPA}, \mathrm{DMC}, \mathrm{DCR}, \mathrm{DRC}\} \quad (5)$$

To use this formula for the assessment of knowledge processing quality (KPQ), the following expert method is proposed.

Each KPQ attribute C_i is rated by experts on a 3-point scale as:

1 — low,
2 — moderate,
3 — high.

On this basis, the value of the Knowledge Processing Quality (KPQ) is calculated as the product of all attributes C_i.

$$\mathrm{KPQ} = \prod_{i=1}^{5} C_i \quad (6)$$

The result of the assessment is to assign them to one of five KPQ classes, namely:

- Rank 1 to 4 — very low (VL),
- Rank 6 to 12 — low (L),
- Rank 16 to 48 — moderate (M),
- Rank 72 to 108 — high (H),
- Rank 162 to 243 — very high (VH).

The last step of the knowledge management process is the assessment of the knowledge maturity level. Maturity models describe how an entity develops through the levels over time until it reaches the fully satisfactory level. Maturity models have the following general properties (Klimko, 2001; Weerdmeester et al., 2003; Schumacher, Erol and Sihn, 2016):

- the development of an entity described with a limited number of maturity levels (usually, between four and six);
- maturity levels are characterised by certain requirements to be achieved by the entity on given level;
- maturity levels are ordered sequentially, from an initial development level up to a fully satisfactory level;
- during the development, the entity progresses step by step from one level to the next, thus no levels can be skipped.

The proposal is to use the concept of maturity to assess knowledge that is available when making decisions based on Big Data. The assessment of knowledge maturity (KM) should be based on three main criteria, namely, the data veracity value, the information utility value and the knowledge processing quality. Methods for determining these criteria are described above. This concept can be illustrated by the model, which represents the following formula:

$$\mathrm{KM} = \{\mathrm{DVV}, \mathrm{IUV}, \mathrm{KPQ}\} \quad (7)$$

Each knowledge maturity attribute Di is evaluated on a 5-point scale, and on this basis, the value of the Knowledge Maturity Level (KML) is calculated as the product of all attributes D_i.

$$\mathrm{KML} = \prod_{i=1}^{3} D_i \quad (8)$$

The maturity of knowledge can also be assessed on five levels, e.g.:

- Rank 2 to 4 — a very low (insufficient) maturity level (VL),
- Rank 8 to 18 — a low maturity level (L),
- Rank 27 to 48 — a moderate maturity level (M),
- Rank 64 to 80 — a high maturity level (H), and
- Rank 100 to 125 — a very high (fully satisfactory) maturity level (VH).

A very low (VL) maturity level can be identified by a lack of knowledge, while the level L — by weak, imperfect knowledge, the level M — by medium imperfect knowledge, the level H — by strong imperfect knowledge, and the level VH — by complete, perfect knowledge.

4. Assessing the disruption risk based on the knowledge maturity concept — an example

The example demonstrates how to apply the method, which is proposed in Section 3, in the logistics decision-making process. The problem concerned the assessment of disruption risk in a new distribution channel, in which the modern smart technologies, based on Big Data flow streams, were provided to monitor the supply continuity. To assess the disruption risk for a given risky scenario, the triplet of attributes of this scenario was proposed. This model, developed by Aven (2015), and modified by Bukowski (2019) can be described using the following formula:

$$R(S_i) = (C'_i, P'_i, K'_i) \quad (9)$$

where:

R(S$_i$) — the risk measure for a risky scenario S_i

C'$_i$ — the consequence measure for a risky scenario S_i (e.g. severity of the scenario impact),

P'$_i$ — the uncertainty measure for a risky scenario S_i (e.g. likelihood of the scenario occurrence),

K'$_i$ — the knowledge measure for a risky scenario S_i (e.g. knowledge maturity level for the scenario and its attributes).

In practice, the first two attributes are considered together and presented in the form of so-called risk matrix (ISO, 2008). An example of such a matrix that was used to assess the level of disruption risk for the most adverse scenarios is shown in Fig. 5. In the analysed case, experts concluded that for the most unfavourable scenario, the level of risk was "moderate", which consists of "moderate" impact and "possible" likelihood. However, the final decision depends on the assumed risk acceptability criterion, i.e. determining the division of risk levels into acceptable and unacceptable. The criterion for this division, according to the risk model (9), depends on the level of knowledge maturity that is available to the decision-maker.

The following classification rules have been proposed:

- if the knowledge maturity is Very Low, no risk level is acceptable;
- if the knowledge maturity is Low, only Very Low risk is acceptable;
- if the knowledge maturity is Moderate, Very Low and Low risk is acceptable;
- if the knowledge maturity is High, Very Low, Low and Moderate risk is acceptable;
- if the knowledge maturity is Very High, Very Low, Low, Moderate and High risk is acceptable.

Therefore, to meet the risk acceptability condition, a "high" level of knowledge maturity must be ensured. Using the framework proposed in Section 3, the following steps were made:

- Data Veracity Value appraisement (Tab. 2),
- Information Utility Value estimation (Tab. 3),
- Knowledge Processing Quality evaluation (Tab. 4), and
- Knowledge Maturity Level rating (Tab. 5).

Based on the above calculations, the level of knowledge maturity is insufficient to meet the required condition. To meet it, the levels of both the Data Veracity Value and the Information Utility Value have to increase to the "high" level. This was done by improving the ICT system, which has been achieved by better "Accuracy", "Traceability" and "Realisation compliance". As a result of these treatments, the knowledge maturity rank increased to 64, which cor-

IMPACT ⇨ LIKELIHOOD ⇩	Negligible	Minor	Moderate	Major	Catastrophic
Remote	Very Low Risk	Low Risk	Low Risk	High Risk	Very High Risk
Unlikely	Very Low Risk	Low Risk	Moderate Risk	High Risk	Very High Risk
Possible	Low Risk	Moderate Risk	Moderate Risk	High Risk	Very High Risk
Likely	Low Risk	Moderate Risk	High Risk	Very High Risk	Very High Risk
Certain	High Risk	High Risk	High Risk	Very High Risk	Very High Risk

Fig. 5. Example of an extended risk matrix

Tab. 2. Data Veracity Value appraisement for the given example

Data veracity attributes A_i	0	1	2	Rank
A_1 –Accuracy (ACC)		x		1
A_2 – Clarity (CLA)			x	2
A_3 – Consistency (CON)		x		1
A_4 – Plausibility (PLA)			x	2
A_5 – Traceability (TRA)		x		1
Data Veracity Value (DVV) =				4 - moderate

Tab. 3. Information Utility Value estimation for the given example

Information Utility attributes B_i	1	2	3	Rank
B_1 – Believability (BEL)		x		2
B_2 – Completeness (COM)			x	3
B_3 – Correctness (COR)		x		2
B_4 – Relevancy (REL)			x	3
B_5 – Timeliness (TIM)		x		2
Information Utility Value (IUV) =				72 - high

Tab. 4. Example of the Knowledge Processing Quality evaluation for the given example

Knowledge Processing Quality attributes C_i	1	2	3	Rank
C_1 – Model adequacy (MA)			x	3
C_2 – Parameter accuracy (PA)		x		2
C_3 – Decision correctness (DC)		x		2
C_4 – Communication reliability (CR)			x	3
C_5 – Realization compliance (RC)	x			1
Knowledge Processing Quality (KPQ) =				36 - moderate

Tab. 5. Example of the Knowledge Maturity Level rating for the given example

Knowledge Maturity attributes D_i	VL=1	L=2	M=3	H=4	VH=5	Rank
D_1 – DVV			x			3
D_2 – IUV				x		4
D_3 – KPQ			x			3
Knowledge Maturity Level (KML) =						36 - moderate

responds to the "high" level. After these changes, the decision was made to accept the planned expansion of the supply network for implementation.

Conclusions

Knowledge about applied sciences, such as economics, engineering, management or social sciences, is based on incomplete theories and indeterministic laws. It applies to open systems, in which the initial conditions are not known exactly, and the induction method is usually used. The data, from which information is obtained, comes from observations or measurements, the accuracy of which is limited and often biased. Therefore, knowledge built on this basis cannot be perfect. Consequently, it is necessary to assess the level of knowledge maturity so that rational decisions can be made under conditions of risk and uncertainty.

The paper presents the historical development of logistics concepts from Logistics 1.0 to 4.0. On this basis, the discussion covered dominant challenges for users of the newest logistic systems as well as the most important features that characterise Logistics 4.0 and distinguish it from previous versions. The most important characteristics of Logistics 4.0 are full integration with Industry 4.0, the implementation of Internet of Things, the use of smart systems and solutions, visibility across the entire supply chain, and Big Data Analytics. The basic condition for its fulfilment is access to advanced and reliable IT systems. These systems are based on intangible assets in the form of Big Data. Therefore, the main part of the work concerns the provision and management of knowledge based on Big Data veracity as a prerequisite for the functioning of systems based on the Logistics 4.0 concept. A new model for the assessment of knowledge maturity as a result of Big Data processing was proposed. This framework allows assessing the usefulness of acquired Big Data to make the correct logistics decisions in a risky environment.

The practical example of using the method presented in the paper allows to formulate the following conclusions:

- the process approach allows detecting weak links and bottlenecks not only in production systems but also in data acquisition and processing systems as well as in decision-making processes based on such acquired knowledge,
- it is very important to supplement the currently used methods of operational risk assessment, in particular, disruption risk prediction, with an assessment of the level of knowledge maturity that is available to the decision-maker,
- a high level of knowledge allows making decisions related to a higher level of risk, which, in many cases, can be a source of competitive advantage in both production and service areas.

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Volume 11 • Issue 4 • 2019

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 1 April 2019
accepted: 30 September 2019

pages: 80-91

Dimensionality of an urban transport system based on ISO 37120 indicators for the case of selected European cities

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ABSTRACT

The study aims to assess transport systems in terms of ISO 37120 indicators in selected European cities. Using the principal components analysis, the research identified significantly correlated variables associated with urban transport. Three principal components explained almost 87% of input data variability. The first principal component was mainly related to transportation fatalities, the second component — to the length of bicycle paths, and the third component — to the length of the network used by light passenger public transport. A strong correlation was found between the length of high capacity public transport and transportation fatalities. Furthermore, the analysis proved that the Aalter transport system was an outlier. The paper concludes by identifying several recommendations on the improvement of urban transport management and the development of low-carbon mobility systems.

KEY WORDS

urban transport, ISO 37120, urban management, spatial management, principal components analysis

DOI: 10.2478/emj-2019-0035

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Introduction

Urban development is dominated by and dependent on transport (Tomanek, 2018). According to the United Nations (United Nations, 2016), 56% of the world's population resides in cities, whereas forecasts indicate an increase to 69% in 2050. Approximately 85% of the EU's GDP is generated in cities. Additionally, the European Union claims that passenger transport will increase by about 34% in 2030 and more than 50% in 2050 in comparison to 2005. According to the White Paper (European Commission, 2016), cities should reduce greenhouse gas emissions by 60%. Ribeiro et al. note that road transport is responsible for approx. 75% of CO_2 emissions worldwide (Ribeiro, 2007). Within the economic, social and ecological dimensions, urban development and transport should be consistent with the principle of sustainability.

The paper aims to discover the relationships between key indicators of urban transport, primarily from the point of view of the principles of the ISO 37120 norm. The discussion within the study focuses on some key questions: What does sustainable transport really mean? Why is a new approach to urban transport needed? What do the indicators of transport for smart cities demonstrate? The research problem focuses on determining the possibility of using the ISO 37120 norm to evaluate urban transport. The article shows dependencies between the theoretical and practical considerations of urban transport. Firstly, the paper organises the terminology used in the field of sustainable urban transport. Secondly, the article is concerned with measuring the performance of urban transport in terms of sustainability. The empirical part focuses on the assessment of transport indicators for selected European cities using the principal components analysis. In addition, outstanding transport systems are identified. The article is based on literature studies and the methods of statistical analysis.

1. Literature review

The scientific literature contains many papers on the topic of urban transport. Crainic et al. elucidated that city logistics aimed to reduce the nuisances associated with freight transportation in urban areas while supporting their economic and social development (Crainic et al., 2007). Fistola supposed that urban mobility meant distribution, quality and use of urban activities with ICT as well as needed different users (Fistola, 2017). Moreover, Tirachini et al. analysed a multimodal social welfare maximisation model with spatially disaggregated demand (Tirachini et al., 2014). In one of such works, Neuenfeldt prepared a bibliometric analysis of publications within the context of urban transport. Many et al. pointed out issues of sustainable development in urban areas (Neuenfeldt, 2016). Batagan et al. identified urban development models for sustainability (Batagan et al., 2012). Ahmad and Mehmood argued that enterprise system would have a pivotal role in future smart city settings and would be able to offer social, environmental and economic sustainability (Ahmad & Mehmood, 2015). Ahvenniemi et al. claimed that a general goal of smart cities was to improve sustainability with the help of technologies (Ahvenniemi et al., 2017). The multidimensional and variable character of the sustainability concept makes it difficult to define sustainable transport. Banister guessed that the improvement of urban sustainability in terms of transport was dependent upon the high-quality implementation of innovative systems and the need to gain public confidence and acceptability through active involvement and action (Banister, 2008). Goldman and Gorham identified four emerging areas of innovation: new mobility, city logistics, intelligent system management and livability (Goldman and Gorham, 2006). According to Richardson, physical, psychological and social needs are primary influencers of sustainable transportation indicators for passenger transport (Richardson, 2005). Tab. 1 shows some of the main differentiating features between traditional and sustainable transport.

Contemporary challenges faced by urban centres change the way cities are managed. Dablanc suggested that the provision of appropriate urban logistics services was slow despite growing needs (Dablanc, 2007). Mingardo elucidated how cities should maintain economic growth, stay accessible and, at the same time, improve the quality of life (Mingardo, 2008). The New Public Management model promotes the corporate style of management in the public sector and the use of benchmark, crowdsourcing, reengineering, controlling, outsourcing, and e-governance. Public transport is one of the significant challenges of urban management. According to the European Commission and the United Nations, all activities must be conducted in line with the principles of sustainable development (European Commission, 2007; United Nations, 2016, Winkowska et al., 2019). Noworól showed another way of looking at urban management in terms of transport, which contained management solutions directed at the inside and the outside (Noworól, 2011). On the one hand, it involves identifying a person responsible for the coordination of the flows of people and goods within the organisational structure of the city hall and. It is their task to formulate long-term strategies in this area (Darie et al., 2019). On the other hand, it is the municipal government in cooperation with residents, forwarders, recipients, transport companies and public transport operators who should improve the urban flows of people and goods. Nevertheless, the municipal government should become the initiator of all activities coordinating the urban transport system. Additionally, basic components of the integrated traffic management system include traffic monitoring, the control of traffic lights and

Tab. 1. Main differences between traditional and sustainable transport

Features	Traditional transport	Sustainable transport
Main aim	traffic	people
Primary objectives	traffic flow and speed	accessibility, economic viability, social equity, health and environmental quality
General approach	infrastructure focus	an integrated set of actions to achieve cost-effective solutions
Planning period	short- and medium-term	long-term vision
Scope of activity	administrative area	functional area
Approach to participation	only by an expert	involving of all stakeholders
Evaluation	limited impact assessment	regular monitoring

Source: elaborated by the authors based on (European Commission, 2014).

variable message signs, and the management of the urban public transport. Munuzuri et al. showed the solutions that could be implemented by local administrations to improve freight deliveries in urban environments related to public infrastructure, land use management, access conditions, and traffic management (Munuzuri et al., 2005).

The European Union requires cities to develop sustainable mobility strategies, including both passenger and freight transport. Another important strategic document is the local spatial development plan referring to the location of road and transport infrastructure (European Union, 2007; European Union 2013). Many Polish cities have no such plans. The average planning coverage is 49.6% for cities (30.2% for Poland) and 15.6% for areas that only own a draft version of such a plan (Hajduk, 2016). Additionally, planning coverage is highly uneven, i.e., the planning coverage of Lodz is only 16.1%, but Gdansk has 65.4%.

Contemporary cities need to improve the use of available technical and organisational solutions to improve the current urban transport situation (Hajduk, 2017). There is a demand for innovations regarding the functional and spatial structure of the city (reducing the transport-imposed limitations on life and economy). Modern solutions should replace conventional means of transport. It is necessary to use environmentally friendly means of transport, such as trams, trains or electric vehicles as well as to exploit waterways and alternative fuels. The sharing economy solutions, such as car-sharing, car-pooling and bike-sharing, has become very popular in cities. Thus, Basaric et al. examined findings of user satisfaction surveys, impacts of bike-sharing on modal split and the emissions of pollutants (Basaric et al., 2012). Glotz-Richter created arguments for car-sharing. Local governments should develop park&ride and bike&ride as well as encourage people to cycle and walk (Glotz-Richter, 2012). De Stasio noted that urban mobility plans were important documents of urban transport policy (de Stasio, 2016). On the other hand, cities should use solutions which reduce the attractiveness of cars by limiting allowable parking time, raising parking fees, introducing fees for driving into city centres and create eco-zones.

The measurement of urban transport is rather a great challenge because of a diversified approach to this issue. Medda et al. studied the relationship between transport and business development in the city using the Solow-Vickrey model (Medda et al., 2003). Scientists distinguish two approaches: quantitative and qualitative. Fielbaum et al. proposed a parametric description of cities for the normative analysis of transit systems (Fielbaum et al., 2017). The quantitative approach to measurement is generally easier to measure directly while quantitative data is recognised as more objective, e.g. the length of linear infrastructure, the number of kilometres travelled per vehicle or person, the number of traffic accidents or fatalities, transport expenses or revenues. On the other hand, the qualitative measurement approach to specific transport phenomena is more difficult to estimate with qualitative data relating to different types of information, e.g. user preferences, aesthetic feelings, as well as user perceived convenience and comfort. The next method of dividing transport indicators reflects its economic, social and environmental impacts. Its economic dimension shows the profitability of transport while the social dimension indicates the mobility of a transport user. The environmental dimension reflects various transport emissions. It is, therefore, advisable to use this approach to measure sustainable transport. Nieuwenhuijsen suggested that the improvement in environmental quality needs multi-sectoral approaches to tackle the environmental problems in relations to urban planning, mobility and transport (Nieuwenhuijsen, 2016).

Using the cluster analysis, Huang et al. showed that urban agglomerations of the developing world were more compact and denser than those of the developed countries of Europe or North America (Huang et al., 2007). While Kasanko et al. used the comparative analysis to divide European cities into three groups: compact southern cities, northern and eastern cities with looser structures and lower densities, and central and western cities midway between the extremes (Kasanko et al., 2006). Nicolas et al. assessed the sustainable transport system in the city of Lyon while Schwarz used the principal component analysis (Nicolas et al., 2003; Schwarz, 2010). Since 2014, cities can use the ISO 37120 norm to estimate their performance, which ensures that they are managed sustainably (Fox, 2015; Deng et al., 2017). It measures the efficiency of cities in terms of environmental aspects, including carbon emission, waste production, pollution and water consumption as well as social and economic aspects, such as economic activity, health and education (Dall'O', 2017; Fox, 2018).

Moreno and Garcia-Alvarez compared European countries based on the Resource-Efficiency Capacity Index, in which transport is one of the dimensions. Denmark, Sweden and Finland received the highest ranking (Moreno and Garcia-Alvarez, 2018). Moreover, Persia et al. carried out a comprehensive study to define a methodology able to indicate effective strategies and measures, allowing to increase the sustainability level of different kinds of cities (Persia et al., 2016). Castillo and Pitfield presented the Evaluative and Logical Approach to the Sustainable Transport Indicator Compilation method for monitoring and reporting progress related to sustainable transport (Castillo and Pitfield, 2010). Later and Dziekan evaluated measures in the field of sustainable urban transport by analysing successful mechanisms (Dziekan, 2012). Alonso et al. proposed a sustainability analysis of urban passenger transport systems based on composite indicators using the benchmarking approach (Alonso et al., 2015). According to Dons et al., the Physical Activity through Sustainable Transport Approaches promotes active mobility (Dons et al., 2015). Multidimensional comparative research aims at identifying certain accurateness in statistical collectivity, where units are described using a relatively abundant set of indicators. Multidimensional comparative research is also widely applied in the economy and environmental protection since it enables the assessment of the level of development of analysed objects and serves as a basis for making right decisions concerning, e.g., the assessment of the implementation of sustainable development for chosen protected areas.

Akande et al. obtained similar results by analysing the EU cities using the Principal Component Analysis and (Akande et al., 2019). Moreover, Ling et al. applied the Principal Component Analysis to study the relationship between the transport infrastructure system and the urban macroeconomic (Ling et al., 2018). Additionally, Shen et al. assessed smart city performance in the context of China by applying the entropy method and the Technique for Order Preference by Similarity to Ideal Solution (Shen and Lou, 2018). This study highlighted that in general, Chinese cities were at a relatively low level of smart performance. Lynch (2015) suggested that the ISO 37120:2014 standard helped to compare cities in terms of urban transport and service performance as well as the quality of life. Many scientists analysed transport from a national and regional perspective (Łatuszyńska and Strulak-Wójtowicz, 2013). Moreover, scientists used the latest future-oriented methods to evaluate transport (Ejdys et al., 2015). While Rotoli et al. attempted to integrate fundamental operational parameters in accessibility through rail including a composite approach combining the Data Envelopment Analysis and the Analytic Hierarchy Process (Rotoli et al., 2015). Furthermore, Gonzalez-Garcia et al. evaluated Spanish cities based on the ratio of people at risk of poverty and social exclusion, the unemployment rate, criminogenic ratio, educational places, the level of education, the net disposable income as well as an environmental endpoint (Gonzalez-Garcia et al., 2018). Additionally Zinkeviciute et al. examine problem concerning to implement a concept green logistics with reference to IT applications (Zinkeviciute et al., 2013). Furthermore, Emilia et al. present some of the measure adapted to reduce the greenhouse emissions produced by the transport (Emilia et al., 2012).

The most popular measurement for smart cities is the International Organisation for Standardization 37120: Sustainable Development of Communities (ISO). Lynch suggested that the ISO 37120:2014 standard helped to compare cities in terms of urban service performance and the quality of life (Lynch, 2015). The Open Data Portal of the World Council on City Data (WCCD), which is based on the ISO 37120 international standard on city data, allows the examination and monitoring of 56 member cities (Steele, 2014; Fox, 2015; McCarney, 2015). Most cities are from Europe (31%) and North America (30%).

According to Marsal–Llacuna, the ISO 37120 norm uses 46 basic and 54 additional indicators, including 17 thematic groups, such as economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, safety, shelter, solid waste, telecommunication and innovation, transport, urban planning, wastewater, water and sanitation (Marsal-Llacuna, 2015). Most indicators (ten in total) are focused on solid waste. The wastewater has only five core indicators.

2. Materials and methods

The principal component analysis is a method used to transform initial, observable variables into principal components which can be defined in the same way as the initial variables. Moreover, the principal component analysis allows the reduction of the number of variables without a significant loss of information contained within them and to detect hidden relationships between variables. Principal components are characterised by a linear combination of initial variables, orthogonal with respect to each other, and a decreasing number of the total variance of variables explained by subsequent components as well as the sum of component variances equal to the sum of initial variable variances.

The selection of indicators in transport is an enormous challenge because this issue is approached in many different ways used in the scientific literature, international strategic documents and reports of various organisations. The selection of variables and cities was made based on the ISO 37120 norm (Attachment 2). These were all European cities and core indicators. In the end, the following indicators (diagnostic features) were selected for the analysis: the length of high capacity public transport system per 100 thousands population, the length of light passenger public transport system per 100 thousands population, the annual number of public transport trips per capita, the number of personal automobiles per capita, the length of bicycle paths and lanes per 100 thousand inhabitants, the number of transportation fatalities per 100 thousands inhabitants. The data were analysed using STATISTICA version 13.1. Appendix 1 presents a list of analysed European cities with general characteristics.

The test procedure consisted of several successive stages: (I) the selection of transport indicators and European cities from the WCCD base; (II) the computation of basic statistics; (III) the standardisation of variables (indicators); (IV) the estimation of the number of principal components based on the Kaiser criterion; (V) the determination of eigenvalues of the correlation matrix; (VI) the calculation of eigenvectors of the correlation matrix; (VII) the identification of the value of principal component coefficients; (VIII) the selection of the configuration of variables in the space of the two principal components; (IX) drawing the configuration of objects in the space of the two principal components; (X) finding the recommendations.

3. Results

The research began with computing the basic statistics for transport indicators by measuring the position ($\bar{x}$ — the arithmetic mean) and variability (S_X — the standard deviation; V — the variation coefficient). The most diverse indicator is the number of transportation fatalities, while the least — the number of personal automobiles. Tab. 2 presents information on the general statistics of each indicator. Afterwards, indictors were standardised using the following formula: $\frac{x-\bar{x}}{S_X}$

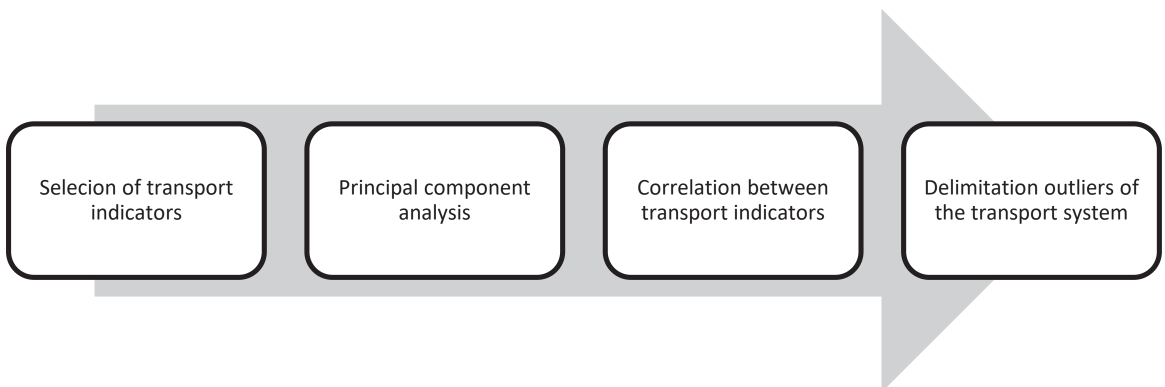


Fig. 1. Research design

Tab. 2. Basic statistics of urban transport indicators

	Units	$\bar{x}$	S_X	V	Min		Max	
HC_PT	kilometres/100,000	18.8981	29.3196	155.1454	0.00	Koprivnica	121.08	Aalter
LC_PT	kilometres/100,000	144.6369	190.6609	131.8204	1.5	Zwolle	670.9	Kielce
PT_T	units/ capita	218.3400	182.5537	83.6098	0.01	Koprivnica	636.5	Porto
PA	units/ capita	0.4481	0.1211	27.0277	0.28	Amsterdam	0.68	Sintra
BP	kilometres/100,000	72.9881	81.7551	112.0115	0.00	Aalter	226.74	Koprivnica
TF	units/ 100,000	3.5494	6.9976	197.1513	0.00	Koprivnica	29.61	Aalter

Legend: HC_PT — the length of high capacity public transport system per 100 000 inhabitants; LC_PT — the length of light passenger public transport system per 100 000 inhabitants; PT_T — the annual number of public transport trips per capita; PA — the number of personal automobiles per capita; BP — the length of bicycle paths and lanes per 100 000 inhabitants; TF — the number of transportation fatalities per 100 000 inhabitants.

Source: elaborated by the authors based on WCCD ISO37120.

The next stage involved determining the eigenvalues of the correlation matrix (Tab. 3). It reflected the significance of the principal components in explaining the information of the input variables. The number of principal components was determined using the method of eigenvalues greater than 1. A higher correlation coefficient of a variable with a component means a higher significance of the variable for a given component.

The subsequent step was the interpretation of the obtained principal components based on the value of their coefficients, which were also the linear correlation coefficients between the input variables and principal components (Tab. 4).

The next stage involved the preparation of shared volatility resources (Tab. 5). The degree of transfer of information resources contained in the input variables by the principal components was assessed using the sum of squares of a principal component for a given variable.

Next, the dependence between input variables and the obtained principal components was presented graphically (Fig. 2). Each variable was represented by a vector. The direction and length of the vectors determine the degree of the impact made by an individual variable on the principal components. The location of an input variable near the circle meant that most of the information contained in this variable

Tab. 3. Eigenvalues of the correlation matrix

Value number	Eigenvalues	Variance [%]	Cumulative eigenvalues	Cumulative Variance [%]
1	2.208224	36.80374	2.208224	36.8037
2	1.628348	27.13913	3.836572	63.9429
3	1.374224	22.90373	5.210796	86.8466
4	0.486512	8.10853	5.697308	94.9551
5	0.242702	4.04503	5.940010	99.0002
6	0.059990	0.99983	6.000000	100.0000

Tab. 4. Values of principal components coefficients

	Principal component 1	Principal component 2	Principal component 3
HC_PT	0.893311	-0.078337	-0.401026
LC_PT	0.204660	-0.417999	0.757983
PT_T	-0.441280	-0.782018	-0.239636
PA	0.465899	0.245224	0.702906
BP	-0.290545	0.879273	-0.100911
TF	0.933878	-0.051766	-0.277807

Tab. 5. Values of shared volatility resources

	Principal component 1	Principal component 2	Principal component 3
HC_PT	0.798004	0.804141	0.964963
LC_PT	0.041886	0.216609	0.791148
PT_T	0.194728	0.806280	0.863706
PA	0.217062	0.277197	0.771274
BP	0.084416	0.857537	0.867720
TF	0.872128	0.874808	0.951985

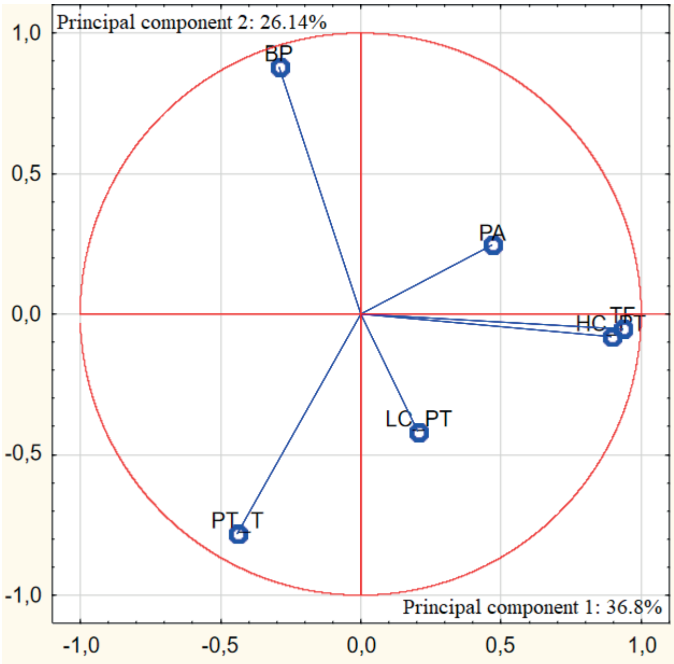


Fig. 2. Configuration of variables in the space of two principal components

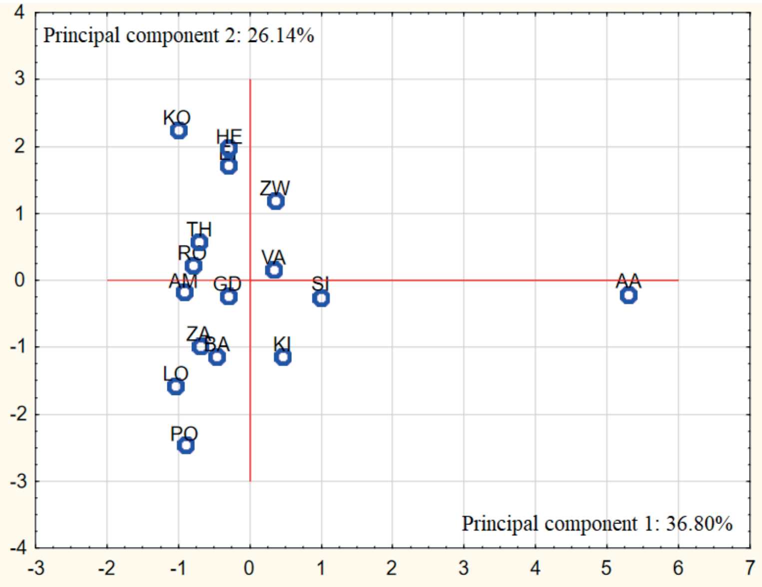
was carried by the principal components. Proximity to two variables informs of a strong correlation. Perpendicular vectors indicate a lack of correlation. Variables positioned on opposite sides are negatively correlated.

The last step of the study involved the identification of outliers based on the configuration of objects in the space of principal components. Fig. 3 presents the graphical location of cities in the space pf two principal components.

4. Discussion

The analysis correlation of dependencies in the group of six highlighted indicators describing the transport system for a selected group of European cities revealed a three-factor structure of this set of indicators, which allowed the reduction of the space of their analysis to three dimensions. The basis for this assessment was the eigenvalues of the correlation matrix of the considered indicators and the degree of variability reproduction using the first three principal components. The variances of the three principal components significantly exceeded the value of 1, indicating a large variation. The three principal components reproduced 86.85% of the total volatility of all analysed transport system indicators. These results can be considered to be satisfactory. The first principal component transferred 36.8% of information about the emissions contained in input variables. The second principal component explains 27.14% of the variability of input data and the last — 22.9%.

Most information resources on the three principal components convert the length of a high capacity public transport system (HC_PT), but only some —



Legend: AA — Aalter, AM — Amsterdam, BA — Barcelona, EI — Eindhoven, GD — Gdynia, HE — Heerlen, KI — Kielce, KO — Koprivnica, LO — London, PO — Porto, RO — Rotterdam, SI — Sintra, TH — The Hague, VA — Valencia, ZA — Zagreb, ZW — Zwolle.

Fig. 3. Configuration of objects in the space of two principal components

the number of personal automobiles per capita (PA). It is respectively 96.5% and 77.13%.

The values of weights indicate that the first principal component is the most positively related to two features, i.e., the length of a high capacity public transport system (HC_PT) and transportation fatalities (TF). On the other hand, the second principal component consists of a positively correlated variable length of bicycle paths and lanes (BP) as well as one that is negatively correlated annual number of public transport trips per capita (PT_T) while the third principal component is most positively related to two features, i.e., the length of light passenger public transport system (LC_PT) and the number of personal automobiles per capita (PA).

The analysis proved that the Aalter transport system was the outlier because there were no bicycle paths and lanes (BP), nor the length of high capacity public transport system (HC_PT) was the highest. Additionally, Koprivnica and Porto transport systems were different.

Conclusions

This paper proposed an assessment for characterising the urban transport of selected European smart cities, which could be used to study this domain from many approached and at different levels. The main contribution of this study is the identification of dependencies between characteristics of urban transport on the basis ISO 37120 norm indicators.

The investigation shows large disparities in the urban transport of selected European cities. The impact of specific analysed factors of sustainable transport in selected European cities can be described by means of three principal components. The first principal component transforms about 37% of the information contained in the input variables. It is responsible for the length of a high capacity public transport system (HC_PT) and transportation fatalities (TF). The second principal component is positively correlated with the length of bicycle paths (BP) and negatively — the number of public transport trips (PT_T). The above correlation testifies the connection of high values of HC_PT with low TF values and, accordingly, the increase of a given variable causes the decrease of the other. Thus, it can be concluded that the principal component analysis is useful in the context of the reduction of variable dimensionality in the description of the problem. The authors would like to note that almost half of the cities come from the Netherlands, which has an impact on the final result of the conducted research.

City leaders should pay more attention to safety when planning public transport in urban areas. All transport users should be provided with access to transport infrastructure and diversified transport modes, with emphasis on low carbon emissions. Integrated planning for transport systems and land use should advance sustainable transport. Developed sustainable urban mobility plans should ensure seamless and door-to-door mobility. They should promote the dialogue on sustainability underpinning the movement of people and goods.

The analysis of the European transport system shows that environmental issues are considered in planning urban mobility. Overall, sustainable transport is still unsystematic in terms of urban activities. The results may provide a valuable tool for decision-makers to identify areas more or less accessible to other zones.

Acknowledgements

The study was implemented within the frame of the scientific project S/WZ/5/2015 supported by the Polish Ministry of Science and Higher Education.

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Attachment 1. Profit of selected European cities

City	Country	Total city population	City land area	Population density	City gross operating budget	City's unemployment rate
	Units	persons	km^2	persons /km^2	million USD	%
AM	Netherlands	834 713	164.66	5 065.0	11 372.8	7.6
EI	Netherlands	224 788	88.84	2 530.3	85 334.8	8.3
HE	Netherlands	87 406	45.53	1 944.0	439.8	8.6
RO	Netherlands	618 357	208.88	2 959.0	4 467.5	12.6
TH	Netherlands	519 988	98.13	5 299.0	-	8.8
ZW	Netherlands	124 896	119.3	1 046.0	543.8	7.0
LO	United Kingdom	8 538 700	1 572.00	5 341.7	18 571.3	7.2
KO	Croatia	30 872	90.94	339.0	15.6	10.4
ZA	Croatia	790 017	641.32	1 232.5	1 112.3	9.6
AA	Belgium	20 218	81.92	247.0	-	3.3
GD	Poland	247 478	135.00	1 831.0	-	4.9
KI	Poland	197 704	110.00	1 797.3	242.1	7.7
BA	Spain	1 611 822	102 16	15 777.4	3 217.5	17.0
VA	Spain	787 266	137.48	5 849.2	896.2	21.7
PO	Portugal	214 329	41.42	5 180.5	351.1	17.6
SI	Portugal	382 521	319.23	1 198.3	127.1	6.3

Note: elaborated by the authors based on WCCD ISO37120.

Attachment 2. Analysed variables for European cities

	HC_PT	LC_PT	PT_T	PA	BP	TF
AM	14.42	26.26	265.04	0.28	76.31	1.48
EI	0.89	52.1	190.01	0.62	204.64	3.14
HE	11.51	114.41	64.88	0.49	222	2.29
RO	13.4	16.05	248	0.34	102.19	1.62
TH	3.63	22.84	111	0.35	85.24	1.55
ZW	46.5	1.5	56	0.41	129	2
LO	14.31	45.1	490.17	0.3	5.86	1.57
KO	0	25.91	0.01	0.38	226.74	0
ZA	3.29	200.12	343.08	0.37	31.64	2.53
AA	121.08	133	27.55	0.53	0	29.61
GD	4.44	97.83	240	0.54	22.61	0.4
KI	11.63	670.9	177.23	0.48	25.8	3.03
BA	15.89	58.16	441.86	0.48	6.51	1.36
VA	14.43	58.72	158.45	0.59	21.09	2.27
PO	18.85	289.12	636.5	0.33	6.95	1.85
SI	8.1	502.17	43.66	0.68	1.23	2.09

Note: elaborated by the authors based on WCCD ISO37120.

Volume 11 • Issue 4 • 2019

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 10 April 2019
accepted: 15 October 2019

pages: 92-102

Influence of technology on regional brands in Czechia

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ABSTRACT

This article aims to examine the effects of new technology on the purchase of regional brands in Czechia and draw conclusions that will help to adapt the brands to customer needs. Regional brands are a speciality of Central Europe, which emerged due to consumer dissatisfaction with low-quality of global retail products. These traditional local handmade products are heavily influenced by new technology and customers requiring them to be purchasable online with a massive online presence. The sample consisted of 1050 residents of the Czech Republic. The data were gathered by a professional marketing agency Ipsos using a questionnaire survey. The sample was tested using the one-way Chi-square test, which had good compliance to test the basic sample characteristics, followed with the one-sample Kolmogorov-Smirnov test to test the data distribution, and then, the dependencies were tested with the Kruskal-Wallis test. Finally, a post-hoc test suitable for the type of analysis could be chosen to better understand the type of factors that could influence the results and their possible effect. The main findings indicate a slow change in the demand as customers are neutral in relation to regional brands available from online shops as well as their about social media presence but require them to have a good-quality website. Solutions are proposed using a government-run brand with a platform providing web layouts and hybrid e-shop. The type of content is proposed, indicating the appropriate execution, which should be done based on the researched-derived segmentation criteria.

KEY WORDS

regional brands, regional product, Kruskal-Wallis test, technology

DOI: 10.2478/emj-2019-0036

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Introduction

The analysis of articles from the Web of Science (WoS) and Scopus databases demonstrated that regional brands for regional products were a speciality of Central Europe (Stoklasa and Pitrunová, 2018) and it gained a lot of traction from consumers dissatisfied with low-quality global retail products. However, this scientific area remains under-researched. Regional brands are certified for regional products that are traditional and locally handmade; however, they are nowadays heavily influenced by new technology and "new age" customers who demand them to be purchasable online with a massive online presence. However, the operating principle of regional brands (fan-driven, limited budget) does not allow them to pursue new trends easily. The technological trends that are transforming this industry might be acceptable for multinational companies with sufficient resources; however, regional brands have many limitations and have to selectively choose on what to focus. Thus, the need arises to explore feasible technological advances and their possible incorporation into the way how regional brands function.

A review of the relevant literature has shown a research gap regarding regional branding in general and the impact of technology on regional brands in particular (Stoklasa and Pitrunová, 2018). The initial study into this area (Pitrunová and Stoklasa, 2018) revealed that brands used very limited communication tools, mostly only websites of, sometimes, dubious quality and ignored other online channels. No other articles in WoS and Scopus databases were found to deal with the influence of technology on regional brands and their products (Stoklasa and Pitrunová, 2018). Therefore, this research topic is important to provide some understanding of how the new technology is changing the way regional brands function, and how these new tools can be used to benefit consumers.

This article aims to examine the effects of new technology on the purchase of regional brands in Czechia and draw conclusions that will help the brands to adapt to their customer needs. The regional brands are defined together with the theoretical basis for the research. Next, the methodology is examined. The sample consisted of 1050 residents of the Czech Republic, and the data were gathered by Ipsos using a questionnaire. Following the general presentation of the results, the data were tested using the one-way Chi-square test to examine the basic sample characteristics and their influence on the results. The Kolmogorov-Smirnov test was used for data distribution, the Kruskal-Wallis test was chosen to test the dependencies of the chosen factors, and the post-hoc test was used to understand, which factors had some influence and what type of the influence it was. Finally, the discussion of the results is presented with several recommendations.

1. Literature review

Research into regional brands is relatively new in academic circles (Chalupová and Prokop, 2016; Kašková and Chromý, 2014). Regional brands originated in the Czech Republic in 2005, with only a few brands that later formed the Association of Regional Brands (ARB, 2019). Because regional brands are a speciality of Central Europe, they only became interesting to researchers after their wider spread following 2010 (Stoklasa and Pitrunová, 2018). According to Jadudová et al. (2018), each V4 country has its system of regional brands with the Czech Republic as a model example. Poland has a good system of regional brands as well because all regions in Poland have Local Action Groups promoting local products. In Slovakia, first regional brands started in 2008.

No uniform regional brand definition exists at the moment (Margarisová and Vokáčová, 2016; Stoklasa and Pitrunová, 2018), the official text by the largest Czech regional brand association ARB (2019) claims: "the main objective of regional branding is to highlight individual regions (both traditional, known for example by their preserved nature, healthy environment, folk traditions, or "new" or forgotten), and to highlight the interesting products that arise here. In each of the regions, a regional brand for products has emerged which guarantees, in addition to their quality and friendliness to nature, above all their origin and connection to a certain extraordinary territory." These products are then defined in the following way (ARB, 2019): "Each region in the Czech Republic has its own unique character, given by the natural richness, culture and centuries-old traditions of its inhabitants. Also, the products originating from a certain area carry a part of this nature - the work of local craftsmen and farmers, and part of their souls, is included. Visitors are offered specific hospitality and unforgettable experiences." Čadilová (2011), former head of ARB, adds that "branded products, their promotion and sale, and perhaps a possibility to meet the producers in person and visit workshops or farms strengthen the region's attractiveness for tourists, form its character and have a positive impact on perceiving the region as a whole."

The regional brands must not be confused with a brand of a region. As Wroblewski (2016) states, local authorities are increasingly more aware that each town, commune or a whole region has an image, that can bring many benefits. This image is often transformed into a brand of the whole region. This article does not deal with this area but rather with regional brands.

This system of separate regional brands is coordinated on the national level by ARB, which acts as an umbrella organisation, giving the brands specific image, logo, rules, communication and other advantages. Each brand has its regional coordinator responsible for the management of the brand. The brand is awarded by an independent certification committee (in each region separately) once the uniform rules have been met. A brand is intended for region's visitors, who can explore the region and enjoy the atmosphere in a new, unusual way, as well as residents who can support their local manufacturers by purchasing branded products. Thanks to the brand, manufacturers notably benefit from a joint promotion of their products, new contacts and new forms of cooperation (ARB, 2019).

Regional brands are becoming well known in the Czech Republic (Chalupová and Prokop, 2016). Yet, consumers are becoming confused by all the various brands and what these brands should guarantee (Vokáčová et al., 2017; Chalupová and Prokop, 2016; Stoklasa and Pitrunová, 2018; Stoklasa, 2015). That is why the focus of this article is not on just one out of hundreds of brands but rather on their group with many similar factors. These similar factors are also observed in relation to their customers, such as the demographic factors used for segmentation. For example, Gajanova et al. (2019) concluded that there is a statistical dependence between age and brand loyalty, but no statistical dependence between gender and brand loyalty.

The Technology Acceptance Model (TAM) is a suitable tool to help understand how technology is changing, as well as the purchasing behaviour of consumers. The original TAM has been created by Davis, Bagozzi and Warshaw (1989) to predict the acceptability of an information system. Later, the model has been upgraded to TAM2 by Venkatesh and Davis (2000), and then, TAM3 was designed for e-commerce. However, the model became popular and widely modified for different purposes. Not all of the models can be used for all areas of research. As proven by Ejdys et al. (2019), consumers perceive risk and security differently in technologies offered by the private sector and public institutions. Tripopsukal (2018) proposed a combination of the TAM model and the TOE framework creating an integrated TAM-TOE model. Bauerová and Klepek (2017) proposed a modified version of the theoretical e-grocery shopping acceptance model, which is very suitable for Regional Branding (Fig. 1). The research did not use the whole modified TAM model but rather the ideas behind its way of functioning (e.g. ease of use, usefulness, shopping attitude and intention). For example, Ejdys (2018) indicated that the ease of use could have a statistically significant influence on technology trust. This has a positive impact on the trust in this technology (Mou et al., 2017) and leads to the way these changes manifest on the outside (a circle of new technology changing the consumer behaviour changing the company behaviour etc.) — digital marketing.

Tiago and Verissimo (2014) argued that the rapid growth of the Web has significantly modified the nature of human activities, habits and interactions. Based on their research data, the trend is accelerating

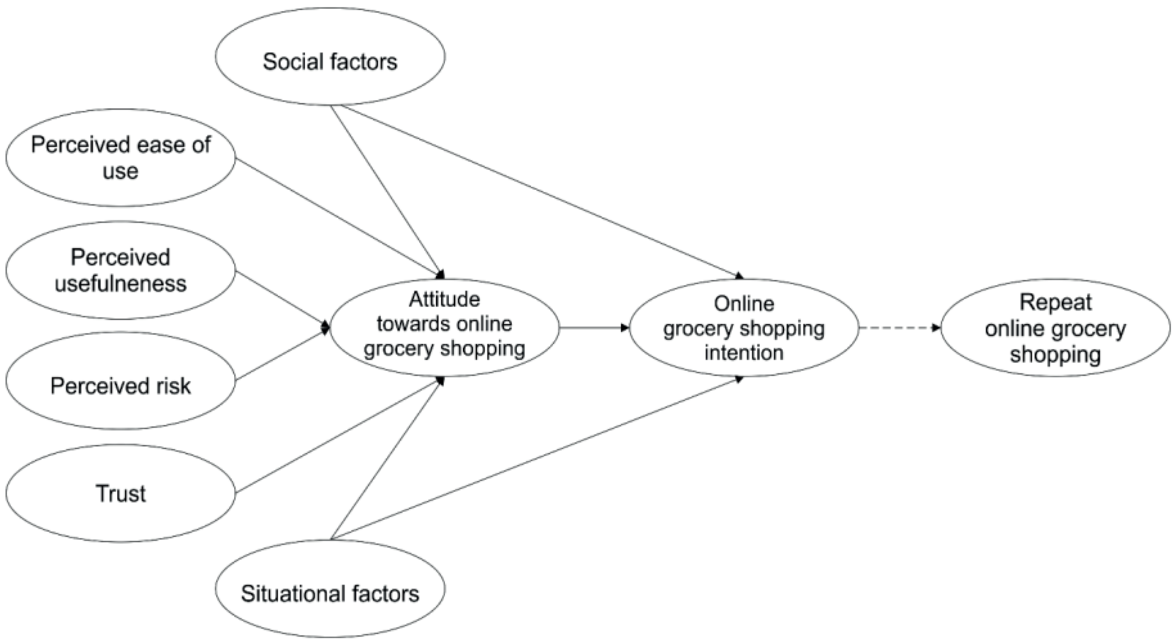

Fig. 1. Theoretical e-grocery shopping acceptance model
Source: (Bauerová & Klepek, 2017).

itself as the rapid growth forces companies to adapt or die. Rust (2019) identified the key technological trends as companies being able to transport more information with their customers and customers utilising more information. This all leads to customers requiring online presence of companies.

Kannan and Li (2017) proposed a framework for research in digital marketing, stating that digital technology influences the environment (consumer behaviour), company (marketing mix) and outcomes. Digital technologies are providing customers with information, change the funnel, expectations, how companies need to communicate etc. If it is combined with the TAM model and applied to the area of regional brands, it is necessary to focus on customer expectations (e.g., about availability or communication) and the main tools to be used to fulfil them (e.g., web or social networks).

The following working hypotheses were formulated:

- Hypothesis 1: Sample identifiers (age, gender, education, and region) impact research results.
- Hypothesis 2: The availability preference of regional products is affected by consumer identifying factors.
- Hypothesis 3: The website perception of regional products is affected by consumer identifying factors.
- Hypothesis 4: The social media perception of regional products is affected by consumer identifying factors.

2. Research methods

The starting point was a literature review (Stoklasa and Pitrunová, 2018) that uncovered the gaps in areas that needed focus, mainly, consumer perceptions of high-quality products, important characteristics of regional products, characteristics of buyers, general purchasing behaviour when buying these products, and changes due to technology. Regional brands as they are understood in Central Europe are under-researched. It is apparent that technology is changing the way consumers purchase products, so it has to change the way they perceive the purchasing process for regional products as well. This led to a follow-up article investigating the online presence of regional brands (Pitrunová and Stoklasa, 2018). Conclusions were made regarding the message communicated by regional brands about their regional products, channels used, and the type of content, on which they focus. After these two articles, a questionnaire was designed, and the survey was carried out by a professional marketing research agency Ipsos in January 2019. The questionnaire was structured into three parts. This article uses the third part, which focused on the technology behind the TAM model. It was a battery of 19 statements that started with a general question "How important is this statement when purchasing regional products?" It used the Likert scale from "strongly agree" to "strongly disagree". The questionnaire was introduced with a thorough description of regional brands and regional products (with logos, pictures and plenty of text), to make sure the respondents were certain about the topic and terminology.

In econometric statistical testing, the following logic is used: the data needs to be tested, followed by testing the dependencies of variables, and further testing of groups that influence the results. At first, the one-way Chi-Square test of good compliance is used to test basic sample characteristics, i.e. find out, which of these are affecting the research results. Followed with one sample Kolmogorov-Smirnov (further as K-S) test to test the data distribution and whether the tested variable follows a normal distribution. Then, the dependencies can be tested with the two-way Chi-Square, ANOVA or Kruskal-Wallis test, depending on the data distribution from the K-S test. Finally, a post-hoc test suitable for the type of analysis can be chosen to better understand the group of factors that influence the results and how (Saunders, Lewis and Thornhill, 2009; Murakami and Lee, 2015).

The sample consisted of 1050 respondents of the Czech Republic. The data were obtained through questionnaire research conducted by professional marketing research agency Ipsos. As identifiers, it used age, gender, education, region, the size of the place of residence and the frequency of online purchases; however, the last two were not used in this article due to their irrelevance for the topic and space restrictions. The Czech Republic has 14 regions. This identifier was included because the regional brands were of different strength in different regions. The sample characteristics can be seen in Tab. 1 and 2.

The first test used the one-way Chi-Square test of good compliance to check the basic characteristics of age, gender, region and education. The test was performed at a significance level $\alpha = 0.05$, i.e. 5%. Due to space limitations, these four separate hypotheses about the four identifiers were worded into one line.

- H0: Age / gender / region / education do not affect research results.

Tab. 1. Sample profile — gender, age, education

Criterion	Group	Absolute frequency	Relative frequency [%]
Gender	Male	536	51.05
	Female	514	48.95
Age	18-25	166	15.81
	26-35	202	19.24
	36-45	216	20.57
	46-55	179	17.05
	56-65	287	27.33
Education	Primary	115	10.95
	Skilled	375	35.71
	Secondary	398	37.90
	University	162	15.43

Tab. 2. Sample profile - region

Region	Abs. frequency
Praha	149
Středočeský	129
Moravskoslezský	124
Jihomoravský	109
Ústecký	93
Zlínský	63
Jihočeský	60
Olomoucký	59
Pardubický	54
Královehradecký	52
Plzeňský	48
Vysočina	48
Liberecký	37
Karlovarský	25

- H1: Age / gender / region / education affect research results.

The test criteria were 30.990, 0.461, 256.933 and 239.516. The value of Sig. 0.000 was less than the set value of significance level. Thus, the null hypothesis (H0) on the independence of individual characters was rejected while the alternative (H1) hypothesis regarding the influence of age, region and education on the research results was accepted. The gender identifier had the Sig. 0.497 and the null hypothesis was accepted. It was, therefore, concluded that age, region and education had an impact on the research results.

3. Research results

This article focused on the second battery of statements dealing with the influence of technology on the purchase of regional brands. The battery had a general question: How important is this statement when purchasing regional products? The battery consisted of 19 statements where respondents had to specify their level of agreement on the five-level Likert scale (Tab. 3). For interpretation, the logic of primary school grading was used where 1 (strongly agree) was the best and 5 (strongly disagree) was the worst score. The battery could be broken down into three blocks, where the first focused on availability, the second — on the web, and the third — on social networks.

The first block (statements 1 and 2) dealt with the availability of regional products, as it was one of the research topics in other parts of this research study (other articles), and was a fundamental part of the TAM model. The online availability, e.g. in an e-shop, was preferred by the respondents with 36.6% of positive answers, only 22.1% — negative answers, and an average of 2.8. Mobile applications were not as preferred with only 19.8% of positive answers, 36.6% — negative answers, and an average of 3.2.

The second block (statements 3–11 and 18) dealt with websites. Generally, there were more than 50% of positive answers and low averages (2.3–2.5) for all statements (well designed, good product labels with pictures, easy navigation and search, product delivery options, payment options, reviews) except for mobile optimisation (42%, 2.7), event promotions (41%, 2.7) and reports from events (31.9%, 2.9). Customers have put high stress on the quality of websites.

The third block (statements 13–17, 19 and 12) dealt with social networks and were bundled with newsletters. Respondents reacted similarly to the first three statements about Facebook, the need to post regularly about events, brands and producers, other topics, all with around 30% of positive answers and an average of 2.9. It is worth noting that all of them had around 25% of negative answers. Regular communication on Instagram and YouTube had both around 15% of positive answers, 25% — negative answers, and an average of 3.3. Sharing opinions and experience with other buyers was reflected positively with 54.6% of positive answers and an average of 2.4. Newsletters, the issues were also perceived rather positively with 40.7% of positive answers and an average of 2.7.

Tab. 3. Research results for all 19 statements

No.	Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	To be available online, e.g. in an e-shop	6.9	29.7	41.3	17.0	5.1
2	To be available through a mobile app.	3.7	16.1	43.5	25.3	11.3
3	For the producer to have a well-designed web	10.9	42.1	33.6	9.8	3.6
4	Web has good product labels including photos	16.2	47.0	27.0	6.9	2.9
5	Easy web navigation and search for desired information	15.5	47.8	28.4	5.3	3.0
6	More product delivery options	11.1	46.0	33.4	7.3	2.1
7	Web is optimised for mobile phones	9.0	33.0	39.4	13.1	5.5
8	More payment options	12.3	49.3	30.2	5.5	2.7
9	Web contains event promotions	7.3	33.7	42.7	12.0	4.3
10	Web contains reports from events and more	5.4	26.5	46.7	16.6	4.9
11	Web contains articles about products, producers, production, etc.	10.6	42.3	36.8	7.3	3.0
12	Possibility to send newsletters about special offers	7.7	33.0	40.7	12.9	5.7
13	Make regular events on Facebook about traditions, regions and producers	7.2	23.3	44.4	16.7	8.4
14	Make regular updates on brand and producer news on Facebook	6.0	23.9	46.8	15.4	7.9
15	Make articles/videos on Facebook to inform about other topics in the region without promoting the producers	6.0	23.0	46.6	15.8	8.6
16	Regular communication on Instagram	3.4	12.4	48.7	23.6	11.9
17	Regular communication on YouTube	3.7	11.8	49.5	23.9	11.0
18	Web contains reviews	18.4	43.2	28.6	6.6	3.2
19	I can share my opinions and experience with other buyers	13.9	40.7	33.5	7.7	4.2

Aiming to test the data for dependencies, the data distribution had to be tested first. The one-sample Kolmogorov-Smirnov test was used to test if a variable followed a normal distribution. The table with all the data was not included due to space limitations. All the Asymp. Sig. (2-tailed) were 0.000, which means that the null hypothesis about the normal distribution of the data was rejected and the alternative hypothesis about data not having normal distribution was accepted. The end result being that ANOVA can't be used but the process had to continue with the Kruskal-Wallis test. The result was supported by all the K-S values in normal parameters, most extreme differences and test statistics.

The non-parametric Kruskal-Wallis test was used to test the working hypothesis on the overall availability preference of regional products and chosen sample identifiers. The working hypothesis was converted to statistical in the following wording:

- H0: The availability preference of regional products doesn't differ based on consumer identifying factors.
- H1: The availability preference of regional products differs based on consumer identifying factors.

Statements no. 1 and 2 and identifying factors (age, gender, region and education) were tested. The test was performed at a significance level $\alpha = 0.05$, i.e. 5%.

The Kruskal-Wallis test results (Tab. 4) manifest that the null hypothesis cannot be rejected, and it has to be stated that the availability preference of regional

Tab. 4. Kruskal-Wallis results for the first block of statements no. 1 and 2

Identifier	Results	S. 1	S. 2
Age	Kruskal-Wallis H	7.195	5.855
	Asymp. Sig.	0.126	0.210
Gender	Kruskal-Wallis H	0.036	0.000
	Asymp. Sig.	0.850	0.997
Education	Kruskal-Wallis H	2.030	7.709
	Asymp. Sig.	0.566	0.052
Region	Kruskal-Wallis H	17.901	10.665
	Asymp. Sig.	0.161	0.639

products does not differ based on consumer identifying factors. However, education warrants further investigation.

The non-parametric Kruskal-Wallis test was used to test the working hypothesis on the overall website perception of regional products and chosen sample identifiers. The working hypothesis was converted to statistical in the following wording:

- H0: The website perception of regional products does not differ based on consumer identifying factors.
- H1: The website perception of regional products differs based on consumer identifying factors

Statements no. 3–11 and 18 and identifying factors (age, gender, region and education) were tested. The test was performed at a significance level α = 0.05, i.e. 5%.

Results of the Kruskal-Wallis test shown in Tab. 5 manifest that the null hypothesis cannot be rejected, and it has to be stated that the availability preference of regional products does not differ based on consumer identifying factors. However, 5 of the age results, 6 of the gender results, 3 of the education results and 1 of the region results warrant further investigation.

The non-parametric Kruskal-Wallis test was used to test the working hypothesis on the overall social media perception of regional products and chosen sample identifiers. The working hypothesis was converted to statistical in the following wording:

- H0: The social media perception of regional products does not differ based on consumer identifying factors.
- H1: The social media perception of regional products differs based on consumer identifying factors.

Statements no. 13–17, 19 and 12 and identifying factors (age, gender, region and education) were tested. The test was performed at a significance level α = 0.05, i.e. 5%.

Results of the Kruskal-Wallis test (Tab. 6) manifest that the null hypothesis cannot be rejected, and it has to be stated that the availability preference of regional products does not differ based on consumer identifying factors. However, 3 of the age results, 5 of the gender results and 4 of the education results warrant further investigation.

Tab. 5. Kruskal-Wallis results for the second block of statements no. 3–11 and 18

Identifier	Results	S. 3	S. 4	S. 5	S. 6	S. 7	S. 8	S. 9	S. 10	S. 11	S. 18
Age	Kruskal-Wallis H	3.794	9.120	6.571	6.157	4.183	11.530	18.092	13.455	9.350	4.739
	Asymp. Sig.	0.435	0.058	0.160	0.188	0.382	0.021	0.001	0.009	0.053	0.315
Gender	Kruskal-Wallis H	3.200	1.750	4.493	0.599	0.107	2.703	2.711	0.108	2.742	5.661
	Asymp. Sig.	0.074	0.186	0.034	0.439	0.744	0.099	0.099	0.742	0.098	0.017
Education	Kruskal-Wallis H	6.042	10.807	4.271	2.604	0.814	7.123	5.300	6.261	5.074	2.400
	Asymp. Sig.	0.110	0.013	0.234	0.457	0.846	0.068	0.151	0.100	0.166	0.494
Region	Kruskal-Wallis H	12.440	16.056	16.246	9.974	14.858	7.111	25.969	14.731	9.229	12.442
	Asymp. Sig.	0.492	0.246	0.236	0.696	0.316	0.896	0.017	0.324	0.755	0.492

Tab. 6. Kruskal-Wallis results for the second block of statements no. 13–17, 19 and 12

Identifier	Results	S. 13	S. 14	S. 15	S. 16	S. 17	S. 19	S. 12
Age	Kruskal-Wallis H	0.797	2.523	1.399	7.843	1.283	9.659	26.671
	Asymp. Sig.	0.939	0.641	0.844	0.097	0.864	0.047	0.000
Gender	Kruskal-Wallis H	10.385	12.262	8.446	0.091	0.758	6.426	6.670
	Asymp. Sig.	0.001	0.000	0.004	0.763	0.384	0.011	0.010
Education	Kruskal-Wallis H	2.357	9.486	6.453	14.633	14.508	1.007	5.852
	Asymp. Sig.	0.502	0.023	0.092	0.002	0.002	0.800	0.119
Region	Kruskal-Wallis H	14.123	13.032	14.604	6.250	7.663	10.008	8.259
	Asymp. Sig.	0.365	0.445	0.333	0.937	0.865	0.693	0.826

Hypothesis 1 was accepted, hypotheses 2, 3 and 4 were rejected. Although all the null hypotheses about independency of variables have been accepted, this research process has been specifically chosen for its power to find the groups that influenced the results in post-hoc testing. Out of the 19 tested statements, if common significance level $\alpha = 0.1$, i.e. 10% was considered, 28 showed the dependency of variables, which is 37%. Gender with 11, and both age and education had 8 cases, where they influenced the result, mainly in the website and social networks perception.

4. Discussion of the results

Based on the previous research (described in chapter 3), the following premises were related to the research topics: online availability will be highly preferred; websites will be important, consumers will prefer user experience (UX) to expertise and up-to-date information, and social media will not play any significant role because of age/gender/education structure of the most engaged consumers.

Online availability in e-shops was slightly preferred and mobile — slightly unpreferred, which was surprising. All the studies and other research papers (Bauerová and Klepek, 2018; Statista, 2019) pointed to consumers preferring online and mobile availability. However, Czechs, although being record online shoppers (Statcounter, 2019), do not prefer shopping online for food products (Špačková, 2018). According to Nielsen research (Špačková, 2018), the barriers were the inability to view the product, additional costs, concerns about product quality. However, online grocery shopping services, such as Košík, Rohlík, Plnátaška, Tesco Online, are growing more popular in the Czech Republic. Currently, only two of the regional brands, very small ones, have an e-shop (Pitrunová and Stoklasa, 2018). Using TAM terminology, it could be stated that the attitude is there, intention as well, but repeat purchase is limited due to one of the factors (perceived risk vs ease of use and usefulness).

Website qualities were more in-line with the premise. Consumers prefer good UX, but also require high expertise, and do not need to have an overabundance of content that would be better suited to social media. The most important for consumers was easy use, navigation and search. Respondents placed the same emphasis on product and photo labels. In addition, various payment options were highly preferred. Nielsen research (Špačková, 2018) supports the findings, as the high stress is put on a high-quality website, which needs to be convenient and easy to navigate. Surprising seemed the answers about web content, with the high preference of quality articles about events, products, promotions and more. But respondents ranked those features way below other web factors. The author could not find any explanation other than that such content belonging to social networks.

The first recommendation is based on the culmination of several trends that were observed in the past decade (Stoklasa, 2015) and the results and discussion presented in this article. The online grocery shopping is perceived as only a supporting channel, not the main one (see previous comments). Having an e-shop can be beneficial, but it does not have to be given a high priority for regional brands. Online communication, however, is important. And the number one priority should be a high-quality website, with good product labels and photographs (it overcomes one of the barriers of not seeing the products, see in above). This leads to a belief that investing in the web presence is the best way to spend the limited budget available to regional brands. The characteristics of the web presence were described in the previous paragraph and can be clearly seen in the results, as well as in the previous article by Pitrunová and Stoklasa (2018). Also, they are supported by other researchers, for example, Roy, Rau and Mandal (2017) proved that information related to products is highly important, transaction detail and the quality of the system. Since the brands will need to be focusing on the product labels and photographs, it is also recommended to couple it with a hybrid e-shop as can be see functioning successfully at, for example, “Farma domů” [Farm to your home] (Farmadomů.cz, 2019). Customers can browse the products and order them online but have to pick them up during a specific day or days. This way of purchasing brings together the ease and convenience of online shopping with the possibility to see the products (touch and smell them). But that is only half of the recommendation. The situation with product protective branding in the Czech Republic is confusing to consumers, as there are hundreds of brands (Stoklasa, 2015; Weikert, 2016) that guarantee something, but consumers have no idea what. On top of all these brands is the state-owned “Regionální potravina” [Regional food], a project that has consumed hundreds of millions CZK with questionable results (Stoklasa, 2015; Horáček 2014). Moreover, regional brands are mostly small (micro), run by enthusiasts to help others, with no profit goals, and with a limited budget. That is why the recommendation of a high-quality website with a hybrid e-shop has to be realised using the "Regionální potravina" as a platform. It could finally unite the characteristics that brands guarantee, educate consumers nation-wide, provide an umbrella over all the micro-brands giving them a chance to have a high-quality website having a standardized layout, also cutting the costs. And the largest benefiting group is consumers. After all, the government-run brands have one of their goals as "the generation of market potential is one of the priority tasks of the marketing of these certification systems and must be continuously formed according to the requirements of end consumers" (Michal et al., 2018).

Respondents don't see social media as crucial. Opinions on Facebook communication were neutral, Instagram and YouTube were rather negative, the only positively accepted form of communication was newsletters. Paradoxically, respondents wanted to be able to share their opinions and experience with other buyers. There is a possibility to offer a discussion feature on the website, under the products or in a dedicated forum.

The identifiers will be used to construct recommendations about customer segments. The K-W post-hoc test using a pairwise comparison, the Dunn's test with the Bonferroni correction, can find the statistically significant differences, rank the groups and assign values. It is used to find, e.g., the gender that influences the results and how. In the first battery of statements, the influence of gender was non-existent, but regions played a huge role. In the second battery, the regions showed minimal statistical significance (only 1 of 19 statements) but in terms of gender, it was considerable (11 out of 19). Women wanted to be much more informed about everything (statements 3, 5, 8, 9, 11 and 18), e.g. in terms of web navigation, product labels, more options etc., and women were more positive about the communication on Facebook (statements 13–15), wanted more opportunities to share their experience (statement 19), and were more positive towards newsletters (statement 12). As regards the age, the age group of 46–55 was the most positive (statement 4, 8, 9, 10, 16, 19 and 12), the youngest age group 18–25 was usually the most negative (all statements except for Instagram and YouTube, and 56% of them perceived easy website navigation as essential). Result supporting this can be seen in Jakubowska and Radzymińska (2019), where Czech young-adults presented much weaker health-related and environmental attitudes towards food products than, e.g., the Polish. In regard to education, the more educated people, the more they agreed with more information, more options and more adaptation (statements 4, 8, 10 and 14). Respondents with high-school education preferred Instagram and YouTube (statements 16 and 17).

The second recommendation is to pursue good content on the website, use the same content on Facebook, target women, of 46–55, with higher education. Although the preferences for content on the website were not overly positive, they were still rather positive, and the content was still incredibly important. Because of the age, gender and education structure, it was clear that it does not need to be young and flashy, but can rather be about recipes, good health, traditions, event reports etc. This content then can be recycled on Facebook. It is recommended to ignore Instagram and YouTube for now, meaning to not produce any special content for the said networks.

To summarise, technology is slowly changing the purchasing behaviour of customers buying regional products. These originally traditional, local and, thus, offline products need to have a good website, need to start exploring the possibilities to be available online and be present on social media.

Conclusions

Online availability of e-shops was slightly preferred and mobile availability was slightly unpreferred. In regard to websites, consumers prefer good UX, but also require high expertise, and do not need to have an overabundance of content that would be better suited to social media. The most important features for consumers are easy use, navigation and search. Respondents place the same emphasis on product and photo labels. In addition, various payment options were highly preferred. Respondents do not see social media as crucial. Opinions on Facebook communication were neutral, Instagram and YouTube were rather negative, and the only positively accepted form of communication was newsletters. Paradoxically, respondents wanted to be able to share their opinions and experience with other buyers. The recommendation is aimed at the state-owned "Regionální potravina" that can be used as an umbrella to provide basic online functionality services to all small regional brands. It will help all stakeholders, as the state gets support for local producers, who get their products more easily to customers, who get quality products. A hybrid e-shop variant was also proposed, which is suitable due to the limitations that these brands have.

The sample identifiers were also used to formulate segmentation criteria usable for the online presence of regional brands. Women wanted to be much more informed about everything, e.g. in terms of web navigation, product labels, more options etc., and women were, in general, more positive about the communication on Facebook, wanted to share their experience more, and were more positive towards newsletters. In regard to age, the age group of 46–55 was the most positive, and the youngest age group of 18–25 was usually the most negative. In regard to education, the more educated were the respondents, the more they agreed with more information, more options, and more adaptation. Thus, it is recommended that brands focus on highly educated women of 46–55.

Technology is slowly changing the purchasing behaviour of customers buying regional products. These originally traditional, local and, thus, offline products need to have a good website, need to start exploring the possibilities to be available online and have a limited presence on social media.

The results of this study can be used to improve the functioning of regional brands in the Czech Republic and can serve as guidelines for other countries with similar systems. Technology is changing consumer behaviour and even products that are traditional have to adapt fast. The limitations of this study are mainly related to the lack of previous research studies on the topic and techniques used to evaluate the data. As described in the literature review, the regional brands are only relevant in a small number of countries and there is no validated methodology that could be used. Each of the chosen data analysis techniques has its advantages and disadvantages and there might be better ones to use that were not attempted. Future research should focus on developing a model for technology acceptance in the area of regional brands, including testing various data analysis techniques. Future research might also be focused on the role of online presence in building regional brands.

Acknowledgement

This research was financially supported by the student grant competition project SGS/7/2017: "Acceptance of technology from the perspective of marketing tools."

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Volume 11 • Issue 4 • 2019

Engineering Management in Production and Services

received: 30 July 2019
accepted: 15 November 2019

pages: 103-117

To meet or to connect? Face-to-face contacts vs ICT in cluster organisations

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ABSTRACT

The main purpose of the paper is to explore how cluster organisations (COs) take advantage of direct (F2F) and indirect (ICT) contacts in fulfilling their main roles. The paper addresses the research question: "How important are Information and Communication Technologies at each level of advancement of cluster cooperation?" The research was conducted in 2016 in four purposefully selected cluster organisations representing metal and ICT industry. The basic method of data collection was an in-depth individual interview. The authors applied the qualitative content analysis as the procedure to analyse the interviews. The research sample comprised of 30 cluster members. The research was based on an original theoretical concept referring to the trajectory of the development of cooperative relationships in cluster organisations. Four levels of development of cluster cooperation as well as three main roles of cluster organisation were distinguished. At each level, COs play one of three identified roles: a direct resource supplier (providing access to resources), a broker (facilitating resource exchanges) and an integrator (integrating into different dimensions), which gives a total of 12 specific roles. The research has shown that both direct and indirect contacts were significant both in fulfilling the roles assigned to the cluster organisations as well as in developing the cluster cooperation. It has been also observed that ICT importance was slightly different at each level of a CO's development. Only in one identified role (at level II: Process integrator) the importance of ICT tools was at least as great as F2F contacts. The research study contributes to the literature which refers to the question of face-to-face contacts established in geographical proximity versus the ones set up by using Information and Communication Technologies in cluster organisations. It was noticed that even though ICT plays a significant role in the functioning of COs, they cannot replace face-to-face contacts. They can only be their important complement at every level of CO development. There are also some limitations connected with the qualitative approach, which does not allow the author to generalise the findings. The first limitation is the small research sample. The second limitation is the subjectivity characterising qualitative research, mainly due to the applied techniques of data collection and analysis.

KEY WORDS

cluster, cluster initiative, cluster organisation, ICT, face-to-face contacts, cooperation

DOI: 10.2478/emj-2019-0037

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Introduction

Cluster organisations, also referred to as bottom-up clusters or cluster initiatives (Sölvell et al., 2003, p. 9; Lindqvist et al., 2013, p. 1), are in the focus of attention in the following publication. They are formally established organisations which function at a higher level of aggregation, composed of institutional members that have joined them purposefully and act actively in order to achieve some collective objectives (related to the development of a specific cluster) or individual objectives (aimed at developing their mother organisations) (Lis, 2018, p. 86; Cheba, 2015; Haviernikova et al., 2016; Štverková and Mynarzová, 2017). Clusters are examples of industrial organisations with strong social ties, involving also networks of local enterprises and local institutions

(Elexa et al., 2019). Most publications in scientific literature refer to clusters viewed in geographical or economic categories, yet only a few of them address clusters as organisations.

Meanwhile, the treatment of COs as organisations which function at a higher level of aggregation is extremely valuable when viewed from the perspective of the management sciences, because it forces collective entities to assume an intentional and engaged approach towards the functioning in the structure of a higher rank. At the same time, it also imposes the necessity to provide management to such a complex organisation. The coordination of a CO refers to actions undertaken by both individuals (people who are employed in organisations which are the members of a CO and who are engaged in the activities undertaken by such an organisation) and collective entities (institutional members). Therefore, the level of advancement of a cluster cooperation is, on the one hand, largely determined by the level of development of the relationships of cluster partners (unit level); on the other hand, based on the use of Information and Communication Technologies (in short: ICT), which facilitates contacts not only at the individual but also at the institutional level. ICT refers to technologies that provide access to information through telecommunications (with particular emphasis on communication technologies, such as the Internet, cell phones, and other communication mediums).

Taking the above into account, the purpose of this paper is to explore how cluster organisations (COs) take advantage of direct (F2F) and indirect (ICT) contacts in fulfilling their main roles. The research goes beyond the state-of-the-art knowledge in the clustering literature by exposing a wider view of cluster cooperation, particularly in connection with the role of ICT in the development of cooperation networks based on geographical proximity.

The discourse is organised in the following manner. First, it contains a literature review on the cluster concept and the role of direct (F2F) and indirect (ICT) contacts in the development of cluster cooperation. Second, the paper includes details with regard to the methodology. Third, it reports the empirical results. Finally, discussion and conclusion are provided.

1. Literature review

The concept of a cluster (Porter, 1998, 2000) derives from Porter's earlier publications on international competitiveness, in which he repeatedly emphasises the importance of geographical proximity to achieve competitive advantage (Porter, 1985, 1990). The definition of a cluster by Porter includes its most important attributes, namely geographical concentration, sectoral concentration and interactions among enterprises, being a derivative of the two previously mentioned attributes. A small distance favours the establishment and development of contacts, whereas sectoral concentration enables to create various systems of connections based on the similarity or diversity of enterprises operating in a cluster. The heterogeneity of cluster partners is advantageous for the development of vertical links along the value chain, while their homogeneity is the basis for the development of horizontal connections based on coopetition. Numerous and repetitive interactions among enterprises can turn into long-lasting and trust-based relationships. A cluster is also specific owing to its strong specialisation, division of work and key competencies as well as an exchange of complementary resources (Lis and Lis, 2014).

The relations between the location and the competitive advantage were studied by the representatives of classical economics (Smith, 1954) and neoclassical economics (Marshall, 1890). The discussion on industrial clusters is also continued within other theories, including the agglomeration theory (Scitovsky, 1954; Perroux, 1950; Krugman, 1991), which explains the reasons for the formation of industrial clusters, the theory of transaction costs (Williamson, 1985) (which emphasises the possibility of reducing transaction costs due to the cooperation of cluster partners), the theory of flexible specialisation (Piore and Sabel, 1984; Sabel, 1989), and the network approach, which exposes the relationships among companies remaining in different dependencies (Cooke and Morgan, 1993; Johanson and Mattson, 1993). All these theories address the significance of trust as an important determinant of cooperation, bringing benefits to all the cooperating entities, as well as geographical proximity, facilitating the development of relationships.

The assumptions of cluster cooperation are also consistent with the resource approach. Companies operating in clusters and cooperating with one another to exchange resources reflect the Resource-Based View (Wernerfelt, 1984; Mahoney and Pandian, 1992; Barney, 1991), which grows out of the company growth theory (Penrose, 1959) and the resource dependency theory (Pfeffer and Salancik, 1978). According to the resource approach, a company is perceived as a bundle of specific resources, abilities and competences that distinguish them from the competitors. The resource approach also emphasises the resource imperfection of a company that is unable to create or acquire all the necessary resources. Dependence on resources is a factor that drives entities to enter into more or less stable exchange relations with other organisations (Pfeffer and Salancik, 1978). As best shown by the concept of clusters (in the form of cluster organisations), obtaining wider access to missing resources encourages companies to create alliances in a form of inter-organisational ties with a non-hierarchical and non-market character (Czakon, 2011). Enterprises in clusters have access to various types of resources, including, first of all, information and knowledge, circulating "in closure" (Coleman, 1988). In clusters, the observed effect of tacit knowledge spillover (Audretsch and Feldman, 1996; Feldman, 1994; Beaudry, 2001; Beaudry et al., 2000; Lawson and Lorenz, 1999) is based on personal, face-to-face interactions, which are facilitated by geographical proximity.

Cooperation in clusters also illustrates the concept of the value chain developed and popularised by Porter (Porter, 1985). According to this concept, a company is a set of activities carried out to design, produce and market a final product, enabling to create value for customers. Actions that prevent a company from gaining a competitive advantage should be scrutinised in terms of their outsourcing to other market players that are able to provide the desired advantage. The effect of this approach is to extend the value chain beyond the boundaries of an individual enterprise. As a result, the value chain becomes a supply chain (Handfield and Nichols, 2002) and even — in a broader sense — a supply network (Christopher, 2005). Cluster cooperation creates opportunities for integration of activities into one common value chain, where competitive advantage is achieved collectively by all the interconnected entities. Due to the special type of cluster relationships (based on coopetition), the value chain in clusters can be extended to a value network, including — apart from suppliers and recipients — competitors and entities providing complementary goods (Nalebuff and Brandenburger, 1996).

2. Role of direct (F2F) and indirect (ICT) contacts in the development of cluster cooperation

The popularity of cluster concept and the widespread use of information and communication technologies in the economy would indicate that approaches combining these both phenomena should appear in the literature quite often. Surprisingly, it is the exact opposite. Searching for scientific publications that include both terms "industrial cluster" and "ICT" resulted in 47 records in the Scopus database and five records in the Web of Science database. What is more, considering the pace of the development of the ICT sector and the dynamics of the modern economy, it must be stated that the vast majority of publications indexed in the previously mentioned databases are outdated (the works published earlier than 2010 dominate). The fact that this is not a new situation is evidenced by the observations contained in the 2008 publication, whose authors expressed astonishment at the small number of scientific papers on the role of information and communication technologies in achieving success by clusters, particularly in the period when a lot of research was conducted on the concept of the cluster (Steinfield and Scupola, 2008). Both of these observations — the very small number of publications related to the use of ICT in cluster enterprises and the low relevance of literature in this regard — lead to the conclusion that there is a large theoretical gap in the problem area undertaken in this paper.

The information and communication technologies present in enterprises have a strong impact not only on the functioning of the company (e.g. improving communication within the value chain) but also, which is perhaps even more important, on creating and applying completely new economic opportunities (Carbonara, 2005), e.g. expansion into new markets. Such possibilities increase owing to the Internet communication characteristics like the speed of transmission, relative easiness of creating and receiving messages by electronic devices, the potential behind processing and analysis of large data sets, etc. The specific nature of ICT also affects cluster companies and clusters as a whole, providing the potential for transforming into one or more effects:

- strengthening the relations of cluster companies with external companies, positively affecting the integration of entities within global supply chains;
- creating an opportunity to establish both lasting and ephemeral contacts with entities outside the cluster;
- broadening the business perspectives of cluster companies;
- managing relations with end markets — offering new services and creating new paths of value creation;

- supporting innovations developed by cluster companies in cooperation with external entities and receiving and adapting innovations from external sources (Carbonara, 2005).

Information and Communication Technologies is, however, a very broad category containing many different products and services. Therefore, the literature highlights the need to make an internal ICT division (Ciarli and Rabellotti, 2007) — at least a division into IT (mainly affecting activities in the sphere of production, administration and logistics) and CT (setting standards for communication within the enterprise and communication with its environment). Each of the division tips indicated above has its specific features and has a different impact on the operation of enterprises.

The needs and adaptability of IT and CT are also to some extent related to the sector, in which the analysed enterprises operate. In sectors offering standard goods, the possibility of using CT is greater because it supports the rapid exchange of codified knowledge and reduces the transaction costs of internal and external communication (Ciarli and Rabellotti, 2007).

In sectors that require better knowledge of a given product/service (Leamer and Storper, 2001), tailoring it to individual customer expectations or the universality of tacit knowledge in the process of producing the offered product/service, face-to-face relationships play a more important role (Leamer and Storper, 2014). Such a situation took place, e.g. in the Italian region of Biella, known for the production of woollen yarns and fabrics, in which local enterprises were more willing to adapt information technologies than communication due to the importance of transferring tacit knowledge in relations between the suppliers and buyers (this region operated with regard to the principle of an industrial district) (Ciarli and Rabellotti, 2007). A similar situation occurred in the case of biotechnology enterprises located in the Medicon Valley — due to the fact that biotechnology products are far from what is commonly understood as standardised products, no information and communication technology here could replace the personal contacts and careful (personal) product selection (Steinfield et al., 2010).

It is worth mentioning that the scientific literature lacks empirical evidence that the hypothesis concerning the substitution of personal contacts for information and communication technologies can be justified. At the current stage of science development, the contemporary level of ICT and the specific nature of interpersonal contacts, we can only talk about the complementarity of these two worlds — human and digital — and their positive impact on the success of cluster enterprises, especially in knowledge-based sectors (Steinfield et al., 2010). ICT cannot entirely replace personal contacts even in the case of a cluster located in rural areas and cluster enterprises scattered over a fairly extensive area. In this case, information and communication technologies compensate for the lack of permanent geographical proximity, but they do not have the potential to make geographical proximity superfluous. Knowledge transfer or a shared pool of workforce qualified to perform activities specific for a cluster located in rural areas are only some of the factors determining the need to conduct business in geographical proximity (Steinfield et al., 2012).

Personal contacts remain irreplaceable in terms of initiating and creating task groups within the cluster. They also constitute a tool to monitor the quality of activities in these groups and to strengthen the motivation of their members. Face-to-face relations facilitate the coordination of activities in groups and are a panacea for uncertainty resulting from constantly changing business conditions. However, to take full advantage of the benefits of cooperation based on personal contacts, permanent cooperation of motivated individuals (not just their occasional contact) with high intellectual capital is necessary. Although ICT allows to decrease the difficulties resulting from the dispersion of production within the value chain (especially in relation to distributed configuration), it is necessary to cooperate in a common location (Storper and Venables, 2004) to deal with uncertainty that may evoke while performing activities in different places, or processes of creating and implementing new solutions. Therefore, with regard to the arguments presented above, it is essential to recognise the specific nature of cooperation among cluster enterprises and the role of information and communication technologies in this area.

3. Research methods

The paper reports the results of an explorative, qualitative study aimed at analysing the role of Information and Communication Technologies in the development of cluster organisations. This is a part of a larger study aimed at identifying the levels of advancement of the cooperation among enterprises in selected COs in Poland (Lis, 2018). The question stated in the current research is as follows: "How important are Information and Communication Technologies at each level of advancement of cluster cooperation?"

The research was carried out in the first half of 2016 in the selected cluster organisations in Poland. In the selection of Cos, the extreme cases logic was used to ensure the maximum variability and diversity within the research field. Taking the economic sector as the main differentiating criterion, four cluster organisations were selected for the study – two COs from the metal industry and two COs representing the ICT industry (Tab. 1). From the point of view of the main aim of the paper, such a research sample provides additional benefits because it serves to compare ICT cluster organisations, in which Information and Communication Technologies are very popular, with COs from the metal industry, in which these technologies are not so commonly used.

The research sample comprised 30 cluster entities (from each of the four selected cluster organisations), including cluster coordinators, enterprises, R&D institutions, educational institutions and support institutions. The way of selecting respondents was based on the snowball sampling procedure (Goodman, 1961). The interviews were the basic technique of data collection. The cluster entities were represented in the study by one person and several cases by two people — in total 35 individual in-depth interviews were conducted. In addition, one group interview was conducted (in Metal Working Eastern Cluster) to verify the obtained results. The group of interviewees was composed of the company owners or top managers as well as individuals chosen to represent the organisation in the cluster organisation involved in cluster activities.

The interview questions were divided into the following sections: forms of cooperation in COs, the involvement of the coordinator and members in COs, creating opportunities and achieving benefits in COs, and flows of knowledge and information in CO. The selection of the above thematic blocks resulted from the objectives set out within a larger study. Nevertheless, each of these blocks may form the basis for more detailed analysis in the areas related to the main research problem of a larger study. As a part of the current research, the following topics were discussed (Tab. 2).

Tab. 1. Sample characteristics

Cluster initiative name	Voivodship	Creation date	Number of cluster members	Number of institutional entities in the research sample	Number of interviews
Metal Cluster of Lubuskie Province	Lubusz	2008	35	9	11
Metal Working Eastern Cluster	Lublin	2009	78	6	7
Mazovia Cluster ICT	Masovian	2007	200	6	6
Interizon: Pomeranian Region ICT Cluster	Pomeranian	2009	130	9	11

Source: elaborated by the authors based on (Lis, 2018).

Tab. 2. Main thematic blocks in the study

Thematic blocks	Thematic scope
Forms of cooperation in COs	– Forms and level of advancement of cooperation in CO, – The role of face-to-face contacts and direct communication in initiating and developing cooperation in CO, development of relationships and building trust in CO, – The role of ICT and distance communication in initiating and developing cooperation in CO
Involvement of the coordinator and members in COs	– Involvement of cluster coordinator in cluster activity (common activities), – Involvement of cluster members in cluster activity (common activities), – Roles of CO in particular areas, – The role of face-to-face contacts and direct communication in fulfilling the roles of CO, – The role of ICT and distance communication in fulfilling the roles of CO
Creating opportunities and achieving benefits in COs	– Opportunities created in CO (with particular emphasis on face-to-face contacts and ICT), – Benefits achieved as a result of participation in CO (with particular emphasis on face-to-face contacts and ICT)
Flows of knowledge and information in CO	– Knowledge and information flows in CO: internal transfer, acquisition and transfer outside, creation (based on cooperation), codification, – The role of face-to-face contacts and direct communication in knowledge and information flows in CO, – The role of ICT and distance communication in knowledge and information flows in CO

Source: elaborated by the authors based on (Lis, 2018).

The data analysis and interpretation were based on content analysis and coding. The study ensures methodological and data triangulations since in addition to the interviews, the author provides an analysis of the current data, including the COs' documents, as well as any means of using Information and Communication Technologies by the COs, such as websites, social network accounts, knowledge repositories, Internet forums, etc.

The authors applied the qualitative content analysis (Hsieh and Shannon, 2005; Glaser and Strauss, 1999) as the main procedure to analyse the interviews. The analysis included open, axial and selective coding. At the open coding stage, some common themes emerging from the interviews in each cluster organisation were identified (for instance, these were 'integration', 'broker', 'information system', 'mentor'). In the axial coding, the identified themes were classified with respect to the six distinguished categories and their peculiarities (Tab. 3). In the selective coding, the categories and their peculiarities were horizontally grouped to feature the general and specific roles, systems, F2F contacts and Information and Communication Technologies in each level of cooperation. The results of selective coding are presented in Tables 5–7 and discussed in the next section.

4. Results

Based on the research conducted in selected cluster organisations, it has been established that cooperation in COs can take different forms, which separated into sets, can form a hierarchical system consisting of four levels of cooperation: level I "Integration at the unit level", level II "Allocation and integration at the process level", level III "Impact on the environment" and level IV "Creation and integration at the organisational level" (Lis, 2018, 2019). As the research survey indicates, despite the differences among the four stages of development of cooperative relationships, cluster organisations may assume three fundamental roles at each stage: of a direct resource supplier, a broker and an integrator.

Cluster organisations play analogical roles at the subsequent levels of cooperation, but each of such roles is affected by the specific nature of a particular level. The specification mentioned above allowed the author to distinguish 12 specific roles — three roles at each of the four cooperation levels (Tab. 4).

The research shows that each of the 12 identified roles of cluster organisations was supported by specific ICT tools, although personal contacts always played a significant role in each of them. Tables 5–7, apart from describing each of the roles of a CO, indicate a particular system necessary to fulfil a given role as well as present the observed forms of face-to-face contacts and the applied Information and Communication Technologies.

4.1. Cluster as a direct resource supplier

A cluster organisation, with regard to its first, fundamental function (Direct resource supplier), can take four detailed roles, namely Informer, Donor, Information Tube and Mentor (Tab. 5). The specific nature of this phenomenon has a significant impact not only on the scope and form of direct interactions among cluster members but also on the use of ICT tools.

The research shows that the characteristic feature of a CO in terms of its role of an Informer is the creation of a one-way information flow system (from a cluster coordinator to the cluster members), which is reflected in a set of ICT solutions used primarily to create an efficient communication platform (Intranet, the CO's website, emailing, newsletters). As far as face-to-face contacts are concerned, formal meetings of the cluster members (initiated mainly by a CO), as well as individual meetings of the members with the coordinator, are the ones that prevail. A cluster organisation that acts as an Informer is the engine of activating its members by providing them with various, yet relatively general, information.

As the research shows, a cluster organisation in the role of a Donor still tries to stimulate its members to cooperate, but changes and extends the scope of its activities, applying additional types of resources (at this level, a CO offers material, capital and human resources). Such a CO still provides information; however, it is more carefully selected to meet the members' needs and expectations. The ICT tools used in this type of CO are also different: apart from the basic solutions that are successful in communication among cluster members, facilities such as knowledge repositories, databases, specialised software to support different phases of the production process or an e-learning platform appear. In terms of F2F contacts, meetings of the members and participation in trainings and workshops dominate.

Tab. 3. The axial coding

No.	Category	Peculiarities
1	Levels of cooperation	• Level I "Integration at the unit level", • Level II "Allocation and integration at the process level", • Level III "Impact on the environment", • Level IV "Creation and integration at the organisational level"
2	General roles	• Direct resource supplier, • Broker, • Integrator
3	Specific roles	• I.1. Informer, • I.2. Information exchange platform, • I.3. Social integrator, • II.1. Donor, • II.2. Resource exchange platform, • II.3. Process integrator, • III.1. Information tube, • III.2. Connector with the environment, • III.3. Lobbyist-visionary, • IV.1. Mentor, • IV.2. Common resource creation platform, • IV.3. Organisation integrator
4	Systems	• One-way information flow system (inside CO, from outside CO), • Two-way information flow system (inside CO, from outside CO), • Information selection system, • One-way knowledge flow system (inside CO), • Two-way knowledge flow system (inside CO), • One-way resource flow system (inside CO), • Two-way resource flow system (inside CO), • Social integration system, • Process integration system, • Cooperation management system, • Institutional integration system, • Environment monitoring system, • System of impact on the environment
5	Common activities based on F2F contacts	• Meetings within CO, • Meetings with people representing key external actors, • Events, • Trainings, workshops, • Internships, • Specialist advice, • Meetings within task groups, • Meetings within project groups, • Meetings within different forms of cooperation
6	ICT	• Platform for communication, • Profile on social networks, • Platform for collecting and selecting information, • Platform for resource exchange, • Educational portal, • Platform for placing group orders, • Joint online sale, • Visual identification system, • Specialised software, • Platform for cooperation management

Source: elaborated by the authors based on (Lis, 2018).

Tab. 4. General and specific roles of cluster organisations

Cat. 1. Levels of cooperation	Cat. 2. General roles	Cat. 3. Specific roles
Level I "Integration at the unit level"	Direct resource supplier	I.1. Informer
	Broker	I.2. Information exchange platform
	Integrator	I.3. Social integrator
Level II "Allocation and integration at the process level"	Direct resource supplier	II.1. Donor
	Broker	II.2. Resource exchange platform
	Integrator	II.3. Process integrator
Level III "Impact on the environment"	Direct resource supplier	III.1. Information tube
	Broker	III.2. Connector with the environment
	Integrator	III.3. Lobbyist-visionary
Level IV "Creation and integration at the organisational level"	Direct resource supplier	IV.1. Mentor
	Broker	IV.2. Common resource creation platform
	Integrator	IV.3. Organisation integrator

Source: (Lis, 2018, p. 226).

Tab. 5. Cluster organisation as a direct resource supplier – F2F vs ICT

Cat. 1. Levels of cooperation	Cat. 2. General roles	Cat. 3. Specific roles	Cat. 4. Systems	Cat. 5. F2F contacts (common activities)	Cat. 6. ICT
Level I "Integration at the unit level"	Direct resource supplier	I.1. Informer	One-way information flow system (inside CO)	Meetings within CO Events	Platform for communication Profiles on social networks
Level II "Allocation and integration at the process level"		II.1. Donor	Information selection system One-way resource flow system (inside CO)	Trainings, workshops	Platform for collecting and selecting information
Level III "Impact on the environment"		III.1. Information tube	Information selection system One-way information flow system (from outside CO) Environment monitoring system	Meetings with people representing key external actors	Platform for communication
Level IV "Creation and integration at the organisational level"		IV.1. Mentor	One-way knowledge flow system (inside CO)	Specialist advice	-

A CO in the role of an Information tube is a one-way transmitter of selected information from outside the cluster. This role of a CO clearly corresponds to the role of an Informer (due to the use of a one-way information flow) yet with a difference: a CO as an Information tube focuses more on monitoring the closer and further surroundings and the transmission of the most important, selected information from outside the cluster to the cluster members. At the level of ICT, similar tools like in the case of the Informer role – the communication platform, such as the cluster's website, Intranet, emailing and newsletters – are used. However, at the level of personal contacts, meetings with the people from outside the cluster become the most important, which can significantly contribute to the development of either the entire cluster organisation or its specific sub-groups.

A CO in the role of a Mentor is a crucial exception among all the roles performed by a cluster organisation: the feature of being both a teacher and a guide for other entities excludes – as it turned out — the intermediation of ICT tools in this area. The emphasis is put on face-to-face contacts, in which the process of one-way knowledge transfer is the most effective. It is related to the peculiar nature of mentoring, which, apart from transmitting official (codified) knowledge, concerns diffusion of tacit knowledge, which is difficult to transfer via ICT tools.

4.2. Cluster as a broker

A cluster organisation in its second form — the broker — plays four detailed roles: as an Information exchange platform, a Resource exchange platform, a Link with the environment and a Common resource creation platform (Tab. 6). The most important factor that distinguishes the previously described form — the direct resource supplier — from the broker is bidirectional communication: information and other resources flow not only from the coordinator to the members but also among some or all the cluster entities.

As the research results show, a CO as the Information Exchange Platform focuses on creating solutions that facilitate the two-way flow of information among cluster members and between cluster members and the coordinator. For this purpose, ICT tools are used, making up a CO's internal communication platform (discussion groups, forums, video and virtual conferencing) as well as creating and maintaining its identity (profiles on Facebook, Instagram, LinkedIn). At the face-to-face level, an important role is played by meetings of various nature (formal, networking and integration), yet which are not focused on the unilateral transfer of information (as it is observed in the form of a direct resource supplier). They aim at creating conditions for better integration and establishing relationships based on mutual trust. This role is also continued by means of events (conferences, seminars, fairs, economic missions) in which the cluster members participate.

The role of the Resource Exchange Platform means creating (by a CO) certain crucial conditions necessary for easy and effective exchange of resources of various types. Similarly to the previously described role (Information Exchange Platform), the Resource Exchange Platform also focuses on the bidirectionality of the transmitted resources. ICT tools used in this role must facilitate an exchange of information with the other cluster members (in relation to competences and resources as well as requirements and needs). Such circumstances improve the implementation of interactive communication platforms, platforms for collecting and selecting information (databases, competence maps) and the ones applied to exchange resources within a given CO (job exchanges, raw material platform, virtual stock exchanges, etc.). At the level of personal contacts, a CO as a broker creates conditions for the cooperation of the members within task groups, conducting trainings by the cluster members themselves, offering internships for the employees of the cluster entities, etc.

Tab. 6. Cluster organisation as a broker – F2F vs ICT

Cat. 1. Levels of cooperation	Cat. 2. General roles	Cat. 3. Specific roles	Cat. 4. Systems	Cat. 5. F2F contacts (common activities)	Cat. 6. ICT
Level I "Integration at the unit level"	Broker	I.2. Information exchange platform	Two-way information flow system (inside CO)	Meetings within CO Events	Platform for communication Profiles on social networks
Level II "Allocation and integration at the process level"		II.2. Resource exchange platform	Information selection system Two-way resource flow system (inside CO)	Meetings within task groups Trainings, workshops, Internships	Platform for communication Platform for collecting and selecting information Platform for resource exchange
Level III "Impact on the environment"		III.2. Link with the environment	Two-way information flow system (from outside CO)	Meetings with people representing key external actors	Platform for communication
Level IV "Creation and integration at the organisational level"		IV.2. Common resource creation platform	Two-way knowledge flow system (inside CO) Cooperation management system	Meetings within project groups Meetings within various forms of cooperation	Platform for cooperation management

As shown by the research, a CO in the role of a Link with the environment concentrates its objectives on creating a two-way system of information flow between cluster members and the surrounding. Therefore, in addition to the fact that such a cluster organisation transmits information from outside to the inside of the CO, it also creates conditions for the flow of information in the other direction: from the CO and its members to their environment. The ICT tools that are considered useful are the ones that function as the Information tube: the CO's website, Intranet, mailing system and newsletter. In the field of F2F contacts, the cluster members establish relationships with selected people from the environment, but in contrast to similar contacts taking place as a part of the Information tube role, the cluster entities can be equal partners, not being only passive recipients of the information transferred by entities from outside the CO.

Being a Common resource creation platform means that a CO provides its members with conditions to establish and develop cooperation oriented towards creation of new resources (e.g. knowledge). The research shows that in this case the technologies that improve group work (e.g. working in the "cloud", groupware software) prove to be useful tools, however, their use is only applicable as a complement to the F2F interactions established within various forms of the cluster cooperation. These interactions usually take a form of project group meetings, in which the representatives of the R & D sector play an important role. It should be noted that the phase of personal contacts must be initial with regard to the use of ICT tools — personal meetings of project team members guarantee the highest level of concentration and efficiency in creating new ICT solutions and motivate the team members to establish relationships based on trust (they are also an excellent opportunity for a multilateral diffusion of implicit and tacit knowledge). ICT tools are therefore successful when a group of people connected by a common, specific goal consciously undertakes actions focused on its implementation.

4.3. Cluster as an integrator

A cluster organisation in its third, the most advanced form (Integrator) plays four detailed roles: as a Social integrator, a Process integrator, a Lobbyist-visionary and an Organisation integrator (Tab. 7). A characteristic feature of this form is the broadly understood integration of various spheres of a CO's activity and a shift of the relation balance among the cluster members from the association pole towards the community pole.

Tab. 7. Cluster organisation as an integrator – F2F vs ICT

Cat. 1. Levels of cooperation	Cat. 2. General roles	Cat. 3. Specific roles	Cat. 4. Systems	Cat. 5. F2F contacts (common activities)	Cat. 6. ICT
Level I "Integration at the unit level"	Integrator	I.3. Social integrator	Social integration system	Meetings within CO Events Training, workshops Internships	Support from the communication platform
Level II "Allocation and integration at the process level"		II.3. Process integrator	Process integration system	Meetings within task groups Meetings within different forms of cooperation	Support from the communication platform Specialised software Platform for placing group orders Joint online sale Visual identification system
Level III "Impact on the environment"		III.3. Lobbyist-visionary	System of impact on the environment	Meetings with people representing key external actors Meetings within different forms of cooperation	Support from the communication platform Educational portal
Level IV "Creation and integration at the organisational level"		IV.3. Organisation integrator	Institutional integration system	Meetings within project groups Meetings within different forms of cooperation	Platform for cooperation management

As the research study shows, a CO acting in the role of a Social integrator primarily aims at achieving a state in which the cluster members will establish (to varying degrees — depending on the openness of individual entities) deeper, trust-based relationships. They are strengthened — at the level of personal contacts — by formal and informal meetings and the common participation of the cluster members in various events (such as fairs, exhibitions, conferences, seminars, economic missions, etc.). ICT tools play a supporting role here, maintaining and strengthening the effects of face-to-face contacts. This particularly applies to solutions facilitating a long-distance contact, e.g. e-mails or instant messengers (text and visual).

The Process integrator role means focusing a CO's objectives on the improvement of processes carried out by some or all the cluster members (such as the process of supply, distribution, promotion, quality standards, etc.). In this role, personal contacts developed most often by cooperation within task groups are less important (in comparison to the other roles), which, according to the research findings, can be replaced by certain ICT tools. In this role, a CO can take advantage of relatively many ICT facilities: a communication platform, a platform for joint orders, a joint online system and a common visual identification system.

Acting as a Lobbyist-visionary forces a CO to go beyond the cluster not only in the search for attractive external stimuli, boosting the activity of the cluster members (as it was the case with the roles of Information tube and — partially — the Link with the environment), but, above all, in order to have such an impact on the external environment, which will adapt to the expectations and needs of the CO members. A CO can use the cluster communication platform (website, mailing), but also — in relation to shaping the educational area — the functionality of already existing or established by the CO educational portals. For the role of a Lobbyist-visionary, however, the most important area of influence is defined by direct contacts: meetings with influential people from the CO's environment (having a high position in the hierarchy of power), emphasising own opinions and care for common interests of the cluster members in the form of lobbying activities (e.g. the introduction or removal of specific regulations in the created laws) or co-shaping the regional educational base (creating classes with profiles convergent with the needs of the cluster companies, creating a system of internships, etc.).

The essence of the last of the distinguished roles — the Organisation integrator — is to bring about the total or partial institutional integration of the entities that have remained as autonomous entities. Based on the research, among the ICT tools supporting the processes of institutional integration, we can distinguish the joint use of ERM (Enterprise Resource Planning), CRM (Customer Relationship Management), SCM (Supply Chain Management), accounting, etc. As far as personal contacts are concerned, they may be the result of cooperation among entities within project groups, cooperation at the strategic level (alliances, start-ups, spin-offs) or creation of a joint commercial market offer. However, it should be clearly emphasised that, similarly to the role of the Common resource creation platform, also in the case of Organisation integration the level of personal contacts is the key factor, whereas the sphere of ICT solutions is the subsequent one, ancillary to F2F relationships.

4.4. Cross-sectoral differences

The research results indicate that the surveyed cluster organisations showed some similarities due to industry membership. The cluster organisations representing the metal industry primarily developed level I "Integration at the unit level", assuming the three roles assigned there: I.1. Informer, I.2. Information exchange platform, I.3. Social integrator. They were also highly active at level III "Impact on the environment", playing three roles: III.1. Information tube, III.2. Connector with the environment, III.3. Lobbyist-visionary. Level IV "Creation and integration at the organisational level" was the least developed level in the surveyed metal clusters. The majority of the respondents from these organisations admitted that they had not reached this stage of cooperation. In turn, both cluster organisations representing the ICT industry, in addition to levels I–III, were able to develop the cooperation assigned to the level IV and meet the three goals defined there: IV.1. Mentor, IV.2. Common resource creation platform and IV.3. Organisation integrator.

The research also shows that the cluster organisations from the metal industry put more emphasis on F2F contacts than on ICT solutions. This was particularly evident in comparison with the surveyed ICT organisations, which in turn placed much greater importance on using ICT tools to fulfil the three roles at each distinguished level of development of cluster cooperation. The respondents representing the metal industry showed great interest in establishing contacts with unknown or poorly known members, cared for the development of the relationships with the cluster partners and tried to improve them. Thus, they were very engaged in activities facilitating the personal contacts within the cluster organisation. It was mainly manifested in their participation in the meetings and events organised as a part of the first three levels of the development of cluster cooperation, primarily in the form of forum meetings, trainings, workshops, internships and meetings with people representing the key external actors. Meetings within task groups were a less frequently practised form in this group of cluster organisations, which results from the weak activity of metal organisations in this area. The surveyed cluster organisations from the metal industry rarely used the ICT tools (primarily those reserved for the lowest levels of cluster cooperation, namely a platform for communication and a platform for collecting and selecting information).

As far as ICT cluster organisations are still concerned, the sphere of personal contacts was important. This was evident at all four levels of cluster cooperation development, although – in the case of levels I and III – with a slightly lower intensity than in the cluster organisations from the metal industry. Participation in task groups (assigned to level II), project groups and consortia (level IV), i.e. involvement in activities aimed at developing face-to-face contacts, reached a higher level in the cluster organisations from the ICT industry than in the metal organisations. Meetings organised as a part of these activities allowed the cluster partners to build trust-based relationships, which encouraged the exchange of confidential information and knowledge. As the research shows, ICT organisations take advantage of ICT tools in almost all their activities. At each level of the development of cluster cooperation, ICT organisations used ICT tools to fulfil defined roles (except for role IV.1. Mentor, for which the appropriate ICT solution was not identified). In addition to the tools reserved for the role of a direct resource donor, ICT organisations also used advanced platforms for cooperation management, i.e. tools assigned to the role of a broker and an integrator at the highest level of cluster cooperation (level IV: IV.2. Common resource creation platform and IV.3. Organisation integrator).

5. Discussion of the results

The results of the research show that cluster organisations, fulfilling the roles assigned to them, slightly differ in the combination of factors related to the development of personal relationships of cluster entities and the use of Information and Communication Technologies.

A cluster organisation appearing in its first form — the Direct resource supplier — puts a great emphasis on the sphere of personal contacts: both within the cluster and with external entities. Nevertheless, the applied ICT tools are an important complement to the effects of face-to-face meetings — at least with regard to the roles concerning the distribution of information (Informer, Donor, Information tube). In the role in which one-way transmission of knowledge occurs (Mentor), ICT tools prove to be of little use, because, despite their technological advancement, they are not effective enough at generating an atmosphere and conditions conducive to the diffusion of tacit knowledge.

According to the obtained research results, a CO that takes the role of a Broker focuses its objectives on creating conditions for the functioning of its component entities in which it will be possible to provide bidirectional flow of information (allowing a CO, for example, to establish a relation of exchange). What appears essential to ensure this bidirectionality in the case of the first three described roles (Information exchange platform, Resource exchange platforms and the Link with the environment) is appropriately selected ICT tools. At the highest level of cooperation (a CO in the role of the Common resource creation platform), ICT solutions play a less important role (although they facilitate cooperation). To use these tools effectively, it is vital to initiate the process with establishing a group of CO members joined by both strong relationships and a common goal (the joint creation of new resources).

Due to its specific nature, a cluster organisation in the form of a Direct resource supplier and a Broker correlates with the resource theory – the two mentioned forms of a CO are focused either on ensuring access to a certain pool of new resources (primarily information) or on creating a platform of information exchange co-managed by constituent entities of the cluster organisation. Communication proximity created and maintained with ICT tools in these two forms has a complementary role in relation to the personal contacts established and developed by virtue of geographical proximity.

A cluster organisation acting as an Integrator uses ICT tools for communication purposes primarily among socially integrated member entities, thus with regard to the role of a Social integrator (integration inside the CO) or a Lobbyist-visionary (integration of the cluster members with the closer and further environment). Many more ICT solutions appear in connection with the roles of a Process integrator and an Organisation integrator, which indicates the presence of dedicated software for basically every aspect of the organisation's operation and cooperation. Their application, however, is directly dependent on the prior establishment of face-to-face contacts and the development of stronger relationships characterised by a relatively high level of mutual trust. In the case of the Process integrator and the Organisation integrator roles, ICT solutions implemented by a CO are not likely to be helpful in the development of such relationships — they are only convenient tools for implementing decisions made via direct relations among people representing the cluster constituent entities.

A cluster organisation in the form of an Integrator comprises the concept of a value chain (and in some cases the value network concept) – this particularly applies to the roles of a Process integrator and an Organisation Integrator. As far as the Process integrator is concerned, ICT tools play a predominant role (when compared to their use by the CO in other distinguished roles) – in principle, they can replace the F2F contacts established within geographical proximity. However, in the case of the Organisation integrator, ICT solutions play an important, yet only a complementary role, facilitating the implementation of institutional integration in a specific form. For the Social integrator, ICT tools are expected to be relatively insignificant since the face-to-face contacts facilitated by the geographical proximity of the cluster partners remain irreplaceable. The same issue concerns the role of a Lobbyist-visionary — although ICT solutions can be beneficial to fulfil this role, meetings and personal contacts of the cluster members definitely prevail.

Conclusions

The study findings have indicated a variety of roles fulfilled by cluster organisations via face-to-face contacts and the use of Information and Communication Technologies. The results contribute to the state-of-the-art knowledge in the clustering literature since they have exposed a wider view on cluster cooperation by using the identified cluster roles at every stage of its development. They have also implemented the Resource-Based View, a value-chain concept and emphasised the significance of F2F contacts (established and developed within geographical proximity) as well as ICT in the processes of resource exchange and integration in different dimensions among cluster partners. Additionally, the research augments prior research as it solely addressed cluster organisations, which — contrary to the concept of a cluster — has been scarcely explored so far.

The conclusions from the conducted research indicate the invariably crucial importance of geographical proximity as a factor strongly affecting the functioning of cluster organisations and their members. As the research shows, almost for every role distinguished in the paper, geographical proximity and direct contacts are a prerequisite for the constitution and development of cluster cooperation at a given level. Therefore, even though indirect contacts established and developed based on Information and Communication Technologies play a significant role in the functioning of cluster organisations, they cannot replace face-to-face contacts. This particularly applies to the first level of development of cluster cooperation, when the network of relationships among cluster members is being built (CO as the Social integrator). As the study results show, only in two identified roles (the Process integrator and — to a lesser extent — the Organisation integrator) the importance of ICT tools was at least as huge as F2F contacts. In the case of the other roles (Direct resource supplier and Broker), ICT were an important complement to the face-to-face contacts at every level of the CO development.

The empirical findings can also suggest some practical implications for cluster coordinators and members – they can be treated as a practical tip in the process of development of COs. Cooperation in cluster organisations should always start with building personal contacts among members and only when relationships based on mutual trust are sufficiently developed, it is worth introducing Information and Communication Technologies as a factor facilitating the achievement of the set goals (individual or common).

Due to the research limitations resulting from the specific nature of qualitative research (a relatively small research sample and the subjectivity of qualitative research, which does not allow the author to generalise the conclusions), future research should also include quantitative research to confirm the observed dependencies. It is also advisable that the future research sample should include cluster organisations representing various industries as it will provide a wider universality of the discovered phenomena.

Acknowledgements

The paper in the shorter version entitled "The use of Information and Communication Technologies in cluster organizations" was first presented at the Strategica International Conference – Upscaling Digital Transformation in Business and Economics 2019, Bucharest, Romania, October 10-11, 2019.

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