ISSN 2543-6597

Bialystok University of Technology
Faculty of Engineering Management

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ISMSME
International Society for Manufacturing, Service and Management Engineering

Engineering Management in Production and Services

Volume 15 • Issue 3 • 2023

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

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

Publisher

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

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

Indexation

Journal is indexed in SCOPUS, Ei Compendex, 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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DOFINANSOWANO ZE ŚRODKÓW BUDŻETU PAŃSTWA

Program „Rozwój czasopism naukowych”

Projekt: Rozwój czasopisma naukowego Engineering Management in Production and Services

Kwota dofinansowania: 80 000,00 zł

Całkowita wartość zadania: 80 000,00 zł

Projekt ma na celu rozwój czasopisma naukowego Engineering Management in Production and Services, poprzez publikację ośmiu numerów w języku angielskim oraz upowszechnienie i zabezpieczenie oryginalności publikowanych w nim artykułów.

PROJECT FUNDED FROM THE STATE BUDGET

"Development of scientific journals” Programme

Project: Development of the Engineering Management in Production and Services scientific journal

Amount of funding: PLN 80,000.00

Total value of the task: PLN 80,000.00

The project aims at developing the Engineering Management in Production and Services scientific journal by publishing eight issues in English, disseminating and ensuring the originality of the published articles.

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sciendo

received: 15 December 2022
accepted: 1 June 2023

pages: 1-13

Neural network modelling of non-prosperity of Slovak companies

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ABSTRACT
Early identification of potential financial problems is among important companies' risk management tasks. This paper aims to propose individual and ensemble models based on various types of neural networks. The created models are evaluated based on several quantitative metrics, and the best-proposed models predict the impending financial problems of Slovak companies a year in advance. The precise analysis and cleaning of real data from the financial statements of real Slovak companies result in a data set consisting of the values of nine potential predictors of almost 19 thousand companies. Individual and ensemble models based on MLP and RBF-type neural networks and the Kohonen map are created on the training sample. On the other hand, several metrics quantify the predictive ability of the created models on the test sample. Ensemble models achieved better predictive ability compared to individual models. MLP networks achieved the highest overall accuracy of almost 89 %. However, the non-prosperity of Slovak companies was best identified by RBF networks created by the boosting and bagging technique. The sensitivity of these models is about 87 %. The study found that models based on neural networks can be successfully designed and used to predict financial distress in the Slovak economy.

KEY WORDS
company, Kohonen map, neural network, non-prosperity, predictive ability

10.2478/emj-2023-0016

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Introduction

Prediction of non-prosperity is one of the most crucial issues for academic researchers and practitioners in risk management. Many researchers and economists have proposed prediction models for reliable and early identification of impending financial problems. These effective tools help decrease the potential threats of the company's bankruptcy on the microeconomic and macroeconomic levels. The models assess corporate financial health in various industries using statistical and other approaches. The neural network technique is among the most used

Durica, M., Mazanec, J., & Frnda, J. (2023). Neural network modelling of non-prosperity of Slovak companies. *Engineering Management in Production and Services, 15*(3), 1-13. doi: 10.2478/emj-2023-0016

tools in this field (Chen & Du, 2009; Fathi et al., 2022; Lin, 2009; Sun & Lei, 2021; Dzikevičius & Stabužytė, 2012).

The paper aims to propose models for predicting the financial problems of Slovak companies using several neural networks such as the Multi-Layer Perceptron (MLP) network, Radial Basis Function (RBF) network, and Kohonen map. These models were compared using selected statistical metrics. Finally, companies were classified in the test sample as prosperous and non-prosperous for all neural networks, and based on this, the quality and prediction ability of created models were identified.

It was found that research on the prediction of financial health offers a wide range of theoretical and empirical findings. However, compared to other research in this area, this study offers universal findings for Slovak companies from all industries, as comprehensive results are presented based on a large sample of Slovak companies. Moreover, the research methodology applies a multi-step solution known as the Cross Industry Standard Process for Data Mining (CRISP-DM) methodology with the application of several types of neural networks and machine learning for determining prosperity in Slovak companies and high-performance indicators. This issue is not sufficiently explored in Slovakia. The results help identify the strengths and weaknesses of the company's management.

The main motivation is based on previous research on a comprehensive assessment of the financial condition of Slovak companies. However, this research usually used such traditional approaches as multidimensional discriminant analysis (MDA) or logistic regression (LR). In addition, models are usually country-specific and reflect a specific macro-environment, including economic and legal aspects of country management primarily, and thus, their use and predictive ability can be considerably limited under the conditions of the Slovak economy.

The research gap consists of identifying the prosperity of Slovak enterprises with a multi-step CRISP-DM methodology, multiple neural networks, and such machine learning as the Kohonen map.

The paper is divided into the following parts: a literature review, methodology, results, discussion, and conclusions. The literature review presents theoretical and practical findings from previous research emphasising the estimation of financial distress using neural networks. The methodology clearly describes the complete process of designing an ANN-based model and quantifying performance and the classification ability of companies into groups of prosperous and non-prosperous companies. The results demonstrate that individual and combined MLP-based models achieve a higher overall prediction ability than other neural networks. The discussion compares the findings with outputs from previous research. In addition, the key limitations are described, and new challenges are comprehensively explained relating to the financial condition of Slovak companies in future research. Finally, the major findings are summarised.

1. Literature review

Ravi Kumar and Ravi (2007) summarised research on financial distress, focusing on applications of statistical and intelligent techniques from 1968 to 2005. These techniques include statistical techniques, neural networks, case-based reasoning, decision trees, operational research, evolutionary algorithms, and rough set-based techniques. Perez (2006) also analysed 30 research studies on the neural network for estimating corporate health. Prusak (2018) similarly reviewed important information on previous research on estimating financial distress in Central and Eastern Europe based on a broad research survey from Google Scholar and Research Gate.

Mihalovič (2016) compared the overall performance of prediction models designed for Slovak companies. These models are created based on 236 companies using discriminant analysis and logistic regression. Logistic regression overcomes discriminant analysis. In addition, the results show that the most important indicators include net income to total assets, current ratio, and current liabilities to total assets. Moreover, Mihalovič (2018) proposed a hybrid model for Slovak companies based on financial statements from 2014 to 2017 using a genetic algorithm. The different models include the genetic algorithm neural network (GA-NN) model, the back-propagation neural network (BP-NN) model, and the MDA-based model. The predictive performance of the models determines that the GA-NN model is better than the others.

Balina et al. (2021) considered prediction models among the key tools in insolvency prediction for Polish companies based on such relevant methods as discriminant analysis, logistic regression, and decision trees. Their research primarily focused on construction companies. Geng et al. (2015) found that the accuracy of the neural network model is statistically significantly higher than the accuracy of other

models in different time windows. On the other hand, the accuracy of majority voting is better than a neural network in a three-year and four-year time window. Dube et al. (2021) promoted neural networks as an alternative way of identifying financial problems for companies listed on the Johannesburg Stock Exchange (JSE) from 2000 to 2019. The neural network correctly identifies over 80 % of financial services companies and almost 97 % of manufacturing companies. Moreover, the model detects the problems up to five years before the bankruptcy. Shin and Lee (2002) emphasised that neural networks are an outstanding alternative to traditional methods of predicting financial distress. Horak et al. (2020) designed and compared six models based on Czech industrial companies using support vector machines and artificial neural networks. These models were compared to identify the most relevant model. Their study shows that a neural model is better than a support vector machine.

Zhang et al. (1999) presented potential possibilities for using neural networks to predict financial distress. The neural network classifies companies as healthy and unhealthy better than logistic regression. Korol (2019) applied various models such as fuzzy sets, recurrent and multi-layer artificial neural networks, and decision trees. One of the critical issues is to assess the effectiveness of prediction models. For example, the fuzzy model achieves more than 96 % correct bankruptcy classification one year before bankruptcy.

On the other hand, all dynamic models, such as fuzzy sets, multi-layer neural networks, and recurrent neural networks, demonstrate relevant approaches in estimating financial distress for outstanding results in the six years before the bankruptcy. The effectiveness for all models is more than 80 %. Dynamic models are better than the decision tree model in all years. The results show that the effectiveness of the dynamic tree model decreases with increasing forecast time. Zhou et al. (2010) explained that macroeconomic indicators affect corporate performance. Their findings demonstrate that the accuracy of the neural network model with macroeconomic variables is better for US businesses than the model without these indicators. Horváthová et al. (2021) concluded that neural networks are a suitable tool for identifying potential threats of financial bankruptcy compared to MDA-based models.

Papana and Spyridou (2020) proposed a prediction model for Greek companies based on four methods: linear discriminant analysis, logistic regression, decision trees, and neural networks. These models are based on 50 financial indicators divided into profitability, liquidity, contribution, efficiency, leverage, and other financial ratios. They found that nine indicators, such as earnings before interest and taxes (EBIT) to total assets, current assets to current liabilities, net earnings to total assets, total equity to fixed assets, fixed assets to total assets, total equity to total liabilities, reserves to total assets, and total equity to total assets, have statistically different averages between prosperous and non-prosperous companies. Total results for all proposed models show that discriminant analysis achieves the best overall performance compared to other models for predicting bankruptcy one year before. Conversely, the decision tree was the worst of all the models. Mateos-Ronco and Mas (2011) developed prediction models focusing on agricultural enterprises in Spain.

On the other hand, Becerra-Vicario et al. (2020) proposed a predictive model for Spanish restaurants using logistic regression and a deep recurrent neural network. This research is based on 28 financial indicators classified on efficiency, liquidity and cash flow, profitability, solvency, and non-financial ratios of 460 companies from 2008 to 2017. Data is drawn from the Iberian Balance Analysis System (SABI). The total sample is divided into a training (70 %) and a test (30 %) sub-sample. The results demonstrate that the neural network is better than logistic regression. Liquidity, profitability, and solvency ratios are important indicators. One of the non-financial indicators, such as quality certificate, is also statistically significant in predicting a company's financial distress. Moreover, the dataset includes other non-financial variables such as the company's age and status of belonging to a business chain.

Bagheri et al. (2012) found that the neural network model has better accuracy than the logistic regression model. Lee and Choi (2013) found that the BP-NN model is better than multiple discriminant analysis. These results are based on 100 financial indicators from 229 companies from various sectors, such as construction, retail, and manufacturing (91 companies in financial distress) from 2000 to 2009. These indicators are classified into five groups: growth, productivity, stability, liquidity, and asset quality. Using a t-test, they identified 46, 40, and 58 significant indicators out of all 100 for selected industries such as construction, trade, and manufacturing. First, productivity and liquidity are essential for the construction sector. Second, productivity and stability are important for business companies. And third,

growth, productivity, and stability are the most important indicators of the production sector. In addition, the results demonstrate that asset quality is not an important indicator in all sectors. Finally, their research compared the accuracy of models on the BP-NN and multivariate discriminant analysis. The results show that the BP-NN model performs better in all sectors than discriminant analysis. Nevertheless, the model accuracy is higher than 80 % for the overall sample, regardless of the sectors. Azadnia et al. (2017) similarly estimated the financial distress of companies listed on the Iranian Stock Exchange based on such inputs as growth, profitability, productivity, and asset quality using fuzzy neural networks. This model achieves excellent performance in predicting financial distress. Moreover, Lee and Choi (2013) presented the relative strength of independent variables. At first, the most critical indicator is retained earnings to the total asset as part of stability. Secondly, productivity is important for the construction and manufacturing sectors. Operating income to the total asset has the highest weight (0.50) for construction companies, and the net profit ratio before income tax expense per capita has the highest weight (0.33) for construction companies.

2. Research methods

In modelling the financial status of Slovak companies, data was used of real Slovak companies from their financial statements from 2018 to 2019. This data was drawn from the Amadeus database by the Bureau von Dijk — Moody's Analytics Company based on their financial statements, such as balance sheets, profit and loss statements, and cash flow statements of all companies from the Slovak Republic. The original dataset consisted of partial data from more than 660 thousand companies. These were companies of various size categories (including micro-enterprises, SMEs, and large and very large enterprises) operating in any economic segment. Subsequently, the data were excluded from the database in the case of many companies that, based on the available data, did not continuously perform economic activities within the Slovak Republic or those for which financial data from both periods were unavailable. In addition, all redundant variables and duplicate cases were removed from this dataset. And for further work with the data, it was supplemented with unique anonymous identifiers.

After a detailed cleaning of the initial data, sixteen financial ratios were determined as potential predictors of non-prosperity. In addition, the company size and the industry were identified according to the terminology SK NACE rev. 2 as potential predictors. Finally, these financial and non-financial indicators from 2018 were used to model the financial status of Slovak companies in 2019.

Multicollinearity was analysed using a correlation matrix and variance inflation factors (VIF). Seven of the sixteen variables were excluded because of the high degree of multicollinearity. Thus, only nine financial ratios were finally identified as potential predictors (Tab. 1). These indicators belong to all four types: profitability, leverage, liquidity, and efficiency (activity) ratios.

The latest comprehensive data unaffected by the COVID-19 pandemic are from 2019. Therefore, the status "company in crisis" is used following the Slovak legislation of 2019 as a target variable for modelling non-prosperity in 2019. In total, 9 497 Slovak companies (12.6 % of all companies) have this status. Therefore, these companies represent samples of non-prosperous companies. On the other hand, 66 152 companies (87.4 % of all) are identified as

Tab. 1. List of potential predictors

Ratio	Ratio type	VIF
Asset Turnover Ratio (SAL/TA)	Efficiency (Activity)	1.614
Current Ratio (CA/CL)	Liquidity	1.741
Return on Equity (ROE)	Profitability	1.014
Return on Assets (ROA)	Profitability	2.484
Debt Ratio (TL/TA)	Leverage	1.840
Cash and Cash Equivalents to Total Assets (CASH/TA)	Liquidity	1.239
Return on Sales (ROS)	Profitability	2.323
Non-current Liabilities to Total Assets (NCL/TA)	Leverage	1.025
Liability Turnover Time (TL/SAL)	Efficiency (Activity)	1.776

Tab. 2. Basic descriptive characteristics of the final dataset

Characteristics	SAL/TA	CA/CL	ROE	ROA	TL/TA	CASH/TA	ROS	NCL/TA	TL/SAL
Mean	1.531	1.774	0.159	0.060	0.892	0.332	0.027	0.014	0.808
Median	1.185	0.940	0.127	0.041	0.820	0.219	0.021	0.000	0.626
Variance	1.968	5.260	0.175	0.033	0.366	0.103	0.019	0.001	0.577
Standard deviation	1.403	2.293	0.419	0.180	0.605	0.321	0.136	0.030	0.760
Minimum	0.000	0.000	-1.145	-0.578	0.000	0.000	-0.516	0.000	0.000
Maximum	7.165	16.060	1.492	0.755	2.982	1.988	0.632	0.152	4.040
Interquartile range	1.687	1.362	0.388	0.151	0.778	0.498	0.071	0.007	0.726
Skewness	1.290	2.667	0.175	0.267	0.933	0.830	0.141	2.766	1.863
Kurtosis	1.615	8.006	1.145	1.907	0.679	-0.511	4.029	7.069	3.620

prosperous. Such large disproportionality could significantly distort the models' learning, and especially their predictive ability. Therefore, 9 497 companies were randomly selected to create balanced samples and verified the sample representativeness.

The final data set contained the data of exactly 18 994 companies. Tab. 2 describes the basic statistics of financial ratios in the dataset. The characteristics of variability, especially the standard deviation and interquartile range, point to a relatively high variability of the values of individual variables. It can be deduced that these are not variables with a normal probability distribution based on the skewness coefficient and kurtosis coefficient values. However, this is not a problem because the artificial neural networks used in modelling do not require to meet the normality assumption. In addition to the financial ratios mentioned above, potential predictors were the company size and economic activity category indicators according to the SK NACE nomenclature. Considering the number of individual size categories, micro and small companies were merged into the category of small-sized companies. The second category was medium-sized companies, and the third category was large-sized companies created by merging large and very large companies. The distribution of size categories in a set of prosperous and non-prosperous companies is illustrated in Tab. 3.

The dataset was further divided into training (80 % of the whole) and testing (the remaining 20 %) samples. The test sample is used only for evaluating proposed models. These models are trained on a training sample using a five-fold cross-validation technique to avoid the overtraining problem of the models.

Artificial neural networks (ANNs) were applied to model the non-prosperity of Slovak companies. These models usually achieve a very high predictive ability. Furthermore, Multi-Layer Perceptron networks (MLP) and networks with a radial basis function (RBF) were created as an activation function. These two types belong to supervised learning algorithms. As a representative of unsupervised learning algorithms, Self-Organising Maps (SOM), also called Kohonen maps, were used.

MLPs are multi-layer ANNs. Zacharis (2016) explained that the typical ANN model consists of a three-layer network of interconnected nodes: the input, hidden, and output layers. Ayer et al. (2010) argued that the structure of biological neural networks inspires neural networks. Networks consist of highly interconnected nodes, and their overall ability helps to estimate output. These networks can solve complex problems because each hidden layer can extract features and recognise patterns from the input vector. The process classifies data for modelling the

Tab. 3. Size structure of companies in the final dataset

Category	Status of the company		Total	Percentage of total
	Prosperous	Non-prosperous		
small-sized	7970	8552	16 522	86.99 %
medium-sized	1368	800	2168	11.41 %
large-sized	159	145	304	1.60 %
Total	9497	9497	18 994	100 %

non-prosperity of companies. The sigmoid, hyperbolic tangent or Rectified Linear Unit (ReLU) function is often used as an activation function in these networks. RBF networks are three-layer neural networks, where the first layer is the input layer, the second (hidden) layer is formed by RBF neurons performing individual radial functions, and the third layer is the output layer and is formed by perceptrons. The activating function of process RBF neurons is some of the radial basic functions. The most used is the Gaussian function.

ANNs are created as individual or ensemble classifiers using boosting and bagging. These classification models classify companies into two groups: prosperous and non-prosperous.

Finally, Self-Organising Maps (SOM) developed by Professor Kohonen (so-called Kohonen maps) were applied. The Kohonen maps explain classification problems by creating clusters of neurons with similar properties. These networks (maps) consist of two layers of neurons, with learning taking place in the output layer in the form of competition. Clusters of similar neurons are formed in the output layer, for example, belonging to one of the classification classes. Each input layer neuron is connected to all output layer neurons. The Euclidean distance identifies the best neuron. One of the advantages of the Kohonen map is the visual presentation of any number of inputs through a two-dimensional grid consisting of output neurons. These clusters are interpreted with a two-dimensional lattice in which the same neurons are located close to each other.

The quality of all models is verified based on a testing sub-sample. Thus, a classification table (so-called confusion matrix) is compiled for the companies in this sample. The matrix determines the proportion of non-prosperous companies with correct classification (True Positives, TP) and non-prosperous companies with incorrect classification to prosperous companies (False Negatives, FN). Moreover, the matrix determines the proportion of prosperous companies classified as True Negatives (TN) and False Positives (FP). Based on the classification table, several qualitative metrics were derived. These metrics test the model's quality:

- Overall Accuracy — the ratio of correctly classified companies (in the whole test sample)
$$ACC = \frac{TP + TN}{TN + FN + FP + TP}$$

- True Positive Rate (sensitivity, TPR) — the ratio of correctly classified non-prosperous companies
$$TPR = \frac{TP}{TP + FN}$$

- True Negative Rate (specificity, TNR) — the ratio of correctly classified prosperous companies
$$TNR = \frac{TN}{TN + FP}$$

- Precise (PR)
$$PR = \frac{TP}{TP + FP}$$

- $F1$-score — frequently used measure of quality
$$F1 = 2 \cdot \left(\frac{PR \cdot TPR}{PR + TPR}\right)$$

- Mathews Correlation Coefficient (MCC) — equivalent to the classical Pearson correlation coefficient
$$MCC = \frac{TP \cdot TN + FP \cdot FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}}.$$

Moreover, the Area Under the Curve (AUC) is applied, that is, the area under the Receiver Operating Characteristic (ROC) curve, which relates 1-specificity (1-TNR) with sensitivity (TPR). The maximum (the best) possible AUC value is one. If the AUC value is close to one, the model achieves high classification ability.

The preparation of the dataset, the creation of models and their validation were carried out in the data mining software IBM SPSS Modeler.

The models are designed as conceptual. Using the created models and their validation, an attempt was made to confirm the research hypothesis about the suitability of using neural networks in modelling the non-prosperity of Slovak companies. For a company outside the analysed sample, the output of the created models is a prediction in the form of classifying this company into a group of prosperous or a group of non-prosperous companies. In addition, the models will also determine the confidence of this prediction.

The paper's authors do not deal with deploying models in practice and, therefore, do not indicate how they could be used to predict financial problems. It is expected to validate and modify the created models on more recent data. Probably, other types of modelling algorithms will be used as well. Only then one final model will be created, which will have to be

programmed and used as a software application for real prediction of imminent financial problems.

3. Research results

Data were used from a training sample of 15 235 companies (approx. 80 % of the total number) to create the model. This sample contains 7 629 prosperous and 7 606 non-prosperous companies. The company size (small, medium, and large), industry according to the SK NACE classification and nine financial ratios from 2018 were potential predictors for created models. The aim was to create the best possible models for predicting the non-prosperity in 2019 using such neural networks as MLP and RBF, which belong to supervised learning techniques and SOMs (or Kohonen maps) representing one of the unsupervised learning techniques.

The prediction ability of these models was analysed based on selected metrics calculated from the classification table and the AUC value based on a testing sample including 3 759 companies (approx. 20 % of the total number). Tab. 4 presents and compares these characteristics of the prediction ability for all created models. As demonstrated, the models achieved excellent and comparable results.

Several MLP-type networks were created on the training dataset. The architecture of the MLP network with one layer of hidden neurons, the hyperbolic tangent as the activating function of this layer and descending gradient method as the error minimisation approach proved optimal. The networks were trained as individual classifier MLP_simple and ensemble classifiers using bagging and boosting techniques (MLP_bagg and MLP_boost). The MLP_simple model is a simple topology perceptron neural network with eight neurons in a single hidden layer. It works with all potential predictors, but clearly, the most important is the Debt ratio (TL/TA), which follows from Fig. 1. Other important predictors are Return on Assets (ROA) and Current ratio (CA/CL). The prediction ability of the models is shown in Tab. 4. All these MLP-type models achieved excellent and comparable prediction ability. However, ensemble models achieved a higher predictive ability, which was expected. The MLP_boost and MLP_bagg models achieved the best results because, except for sensitivity (TPR), the values of all other quality characteristics are the highest for these models. The

Tab. 4. Comparison of the characteristics of the predictive ability of the created models

Classifier	*ACC*	*TPR*	*TNR*	*PR*	*F1*	*MCC*	*AUC*
MLP_simple	88.24 %	86.41 %	90.10 %	89.83 %	88.09 %	0.765	0.937
MLP_boost	88.61 %	85.72 %	91.54 %	91.12 %	88.34 %	0.774	0.945
MLP_bagg	88.61 %	86.24 %	91.01 %	90.66 %	88.39 %	0.773	0.944
RBF_simple	83.53 %	84.08 %	82.98 %	83.33 %	83.71 %	0.671	0.910
RBF_boost	85.34 %	87.41 %	83.24 %	84.08 %	85.71 %	0.707	0.928
RBF_bagg	84.49 %	86.94 %	82.01 %	83.03 %	84.94 %	0.690	0.919
Kohonen	80.50 %	80.49 %	80.51 %	80.70 %	80.59 %	0.610	0.895

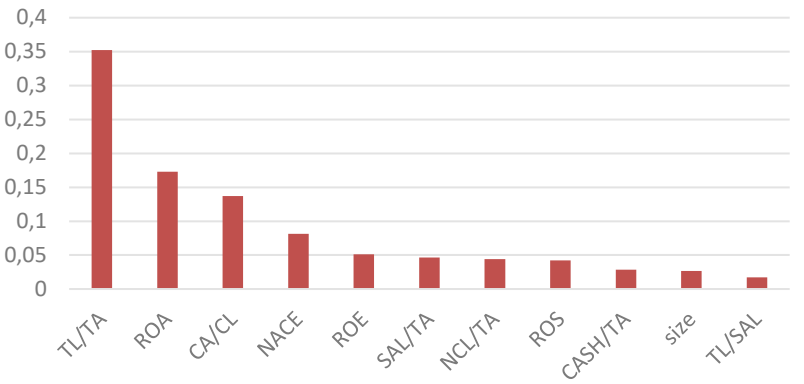

Fig. 1. Predictor importance in model MLP_simple

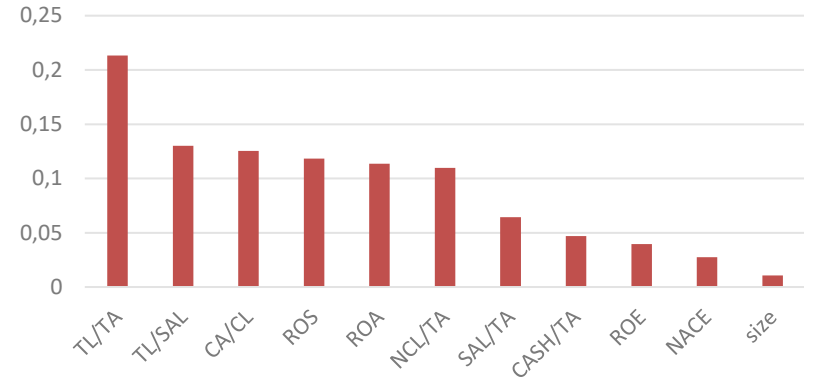

Fig. 2. Predictor importance in model RBF_simple

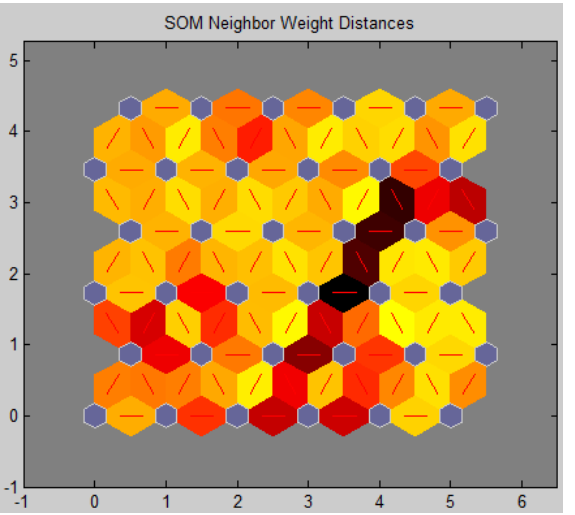

Fig. 3. Kohonen map

MLP_boost model is an ensemble of eleven networks, and the MLP_bagg model combines ten networks. Both models work with all potential predictors, but the most significant are TL/TA, TL/SAL, ROS, ROA, CA/CL, and CASH/TA.

RBF-type networks were also trained with the radial basis function under similar conditions as the activation function. Again, individual and ensemble models were created using the bagging and boosting technique. As shown in Tab. 4, RBF-type models also achieved a very high prediction. However, they do not reach the results of MLP-type models. The ensemble models RBF_bagg and RBF_boost achieved better results than the individual model RBF_simple. Both ensemble models outperform the other models in sensitivity (TPR), so in a set of truly non-prosperous companies, these models have identified companies at risk of financial problems.

The RBF_simple neural network with ten neurons in the hidden layer correctly classified only 83.53 % of companies from the test set. Like the MLP_simple model, this individual model works with all predictors, and the most significant one is the Debt ratio (TL/TA). It is interesting, however, that the values of the other five predictors (TL/SAL, CA/CL, ROS, ROA, and NCL/TA) are approximately equally significant in predicting the prosperity of Slovak companies, which is illustrated in Fig. 2. The mentioned six predictors were also the most significant in the RBF_boost and RBF_bagg ensemble models, where the RBF_boost model is a combination of nine RBF networks, while the RBF_bagg model is an ensemble of ten networks. Interestingly, in both models, all six mentioned predictors are equally significant.

Finally, the Kohonen map was applied to represent unsupervised learning techniques. Only an

individual classifier was created that achieves a high prediction ability (ACC=80.5 %, TPR=80.49 %, TNR=80.51 %, PR=80.7 %, F1=80.59 %, MCC=0.61, and AUC=0.895). However, the prediction power is slightly lower than that of MLP-type and RBF-type networks. Interestingly, the Kohonen map classifies companies equally well in both groups of companies. It is because the difference between the sensitivity (TPR=80.49 %), which is the proportion of correctly classified non-prosperous companies, and the sensitivity (TNR=80.51 %), the proportion of correctly classified truly prosperous companies, is only 0.02 %. The output layer of the Kohonen map (Fig. 3) shows the two classification classes (prosperous and non-prosperous) using "pale" areas separated by a line of dark-red-coloured neurons.

4. Discussion of the results

Several prediction models were created based on several types of artificial neural networks. The models were trained (learned) and validated on precisely prepared data of real Slovak businesses from 2018 and 2019 for all of them from any economic segment and size category. The values of several financial ratios from 2018 serve to predict the financial status in 2019. This status can be the company's prosperity, in other words, the company's financial health, or non-prosperity, that is, the company's financial problems. Based on the validation of the quality of the created models on the test set, all models achieved very good results, illustrated in Fig. 4. In terms of overall predictive ability, the best results were achieved by MLP-based models, as they achieved the highest values in all overall quality metrics (ACC, PR, F1, MCC, and AUC). Compared to the individual classifier MLP_simple, the ensemble models MLP_boost and MLP_bagg achieved better (and thus overall best) results, as they correctly classified up to 88.61 % of the companies in the test set.

However, the mentioned models achieved a relatively lower sensitivity rate (TPR) compared to RBF-based models. Ensemble models of this type achieved sensitivities of 87 %, which means that in a group of non-prosperous companies in 2019, these models correctly identified their non-prosperity in 87 % of cases. The created Kohonen map achieved the lowest results of all models. Therefore, it proved unsuitable for modelling Slovak companies' prosperity.

Based on the results, MLP and RBF networks are suitable tools for modelling the non-prosperity of Slovak companies, especially in ensemble models. It confirmed the validity of the statutory research hypothesis. However, the created models must be further validated on newer data and possibly updated. Only then will it be possible and effective to put them into practice in (not only) Slovak companies from any economic segment and size category. However, some software implementation of the models will be required for this. However, this was no longer the subject of research and this paper.

Constantin and Clipici (2017), Kristianto and Rikumahu (2019) and others developed research on bankruptcy prediction models using neural networks. Similarly, Bielikova et al. (2014), Tumpach et al. (2020), and Korol (2020) examined the financial stability in Central Europe. Using the Kohonen map, Suler (2017) used data from financial statements and other predictors, such as the number of employees in construction companies from 2006 to 2015 in the Southern Bohemian region. On the other hand,

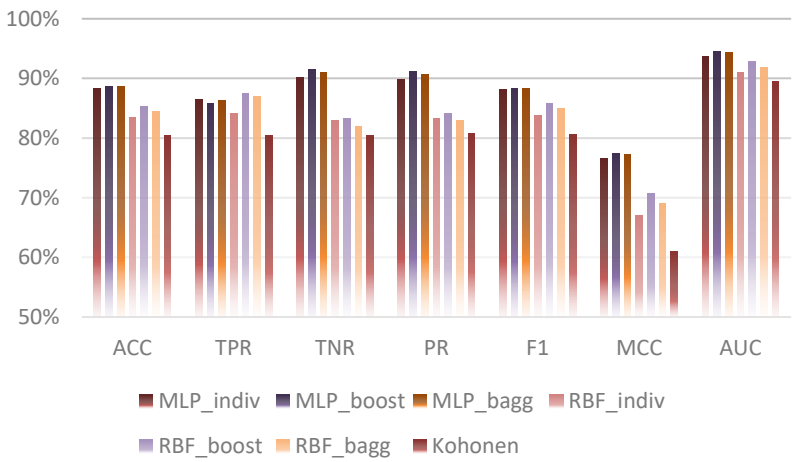

Fig. 4. Graphical comparison of the quality of the created models

a prediction model was proposed for all industries in the Slovak Republic.

Perez (2006) applied a fuzzy neural network for corporate bankruptcy prediction based on data from the companies listed on the Teheran stock exchange. The neural network includes four inputs: growth, profitability, productivity, and asset quality, and the output variable represents Altman Z-score. The model proposed in this paper achieved high model performance in estimating financial failure. It was determined that nine of 16 indicators could potentially estimate financial prosperity in all Slovak industries. These variables are identified based on a comprehensive process aimed at removing redundant indicators because of the high level of multicollinearity. Bagheri et al. (2012) built on previous research on listed companies from the Teheran stock exchange. The research compared ANN and logistic regression. The results demonstrate that neural networks achieved better predictive accuracy than the logit model. On the other hand, the research limitation is the sample size because the total sample consists of only 80 companies.

Similarly, Mokhatab Rafiei et al. (2011) classified healthy and unhealthy companies using ANN, genetic algorithm (GA), and MDA. Compared to other model techniques, the ANN model has the best predictive accuracy, specifically 98.6 % in the training sample and 96.3 % in the testing sample. It was designed based on 180 manufacturing companies on Tehran Stock Exchange for bankruptcy prediction one year before. Neural networks appear to be the popular approach in classifying companies as prosperous and non-prosperous in Iran compared to the Visegrad Group. In this paper, various individual and ensemble models, such as MLP, RBF, and Kohonen maps, were applied to improve predictive accuracy.

Callejón et al. (2013) proposed a neural network based on financial data from thousands of European manufacturing companies from 2007 to 2009. The data were obtained from the Amadeus database by Bureau van Dijk. The sample included 500 active and 500 insolvent companies from Germany, Denmark, Greece, Italy, France, Spain, Portugal, Finland, and Belgium. The indicators were divided into financial stability, profitability, efficiency, and firm size. The total dataset included 17 financial variables. The model correctly classified 92.56 % of companies in the training sample and 92.11 % of companies in a testing sample based on financial data for two years before the bankruptcy. Using the Deep Recurrent Convolutional Neural Network (DRC-NN), Becerra-Vicario et al. (2020) correctly classified more than 93 % of companies one year before bankruptcy, almost 90 % of companies two years before the bankruptcy, and more than 85 % three years before the bankruptcy. Their research filled the research gap in predicting financial failure in the hospitality sector in Spain.

Finally, Alamsyah et al. (2021) proposed three artificial neural models for several periods depending on the years before the bankruptcy. The results revealed that based on data on companies listed on the Indonesia Stock Exchange (IDX), the ANN-BP model achieved better predictive accuracy (95.6 %) for bankruptcy four years before compared to other models, predicting bankruptcy two or three years before.

Tab. 4. Summary overview

Authors	Data	Sample	Method	Country	ACC	TPR	TNR	MCC	AUC
Zhou et al. (2010)	1980–2006	1 924	MLPSig	USA	76.53	75.07	77.98	n/a	n/a
Zhou et al. (2010)	1980–2006	464	MLPSig	USA	78.61	81.37	75.74	n/a	n/a
Callejón et al. (2013)	2007–2009	1 000	MLP	A few EU countries	92.56	94.88	90.28	.85	n/a
Eriki and Udegbunam (2013)	1987–2006	44	NN	Nigeria	80.00	n/a	n/a	n/a	n/a
Ahmadpour Kasgari et al. (2013)	1999–2006	136	MLP	Iran	95.09	93.33	96.49	n/a	n/a
Mihalovič (2018)	2014–2017	1 280	BP-NN	Slovakia	81.15	n/a	n/a	n/a	n/a
Mihalovič (2018)	2014–2017	1 280	GA-NN	Slovakia	91.89	n/a	n/a	n/a	n/a
Becerra-Vicario et al. (2020)	2008–2017	460	DRCNN	Spain	95.00	n/a	n/a	n/a	.975
Our model	2017–2018	18 994	MLP_boost	Slovakia	88.61	85.72	91.54	.774	.945
Our model	2017–2018	18 994	RBF_boost	Slovakia	85.34	87.41	83.24	.707	.928

Horváthová et al. (2021) applied a feed-forward neural network and multivariate discriminant analysis. The results demonstrated that using the Brier score and Sommer's D in the Slovak heating industry, a neural network is better for assessing financial distress. Pakšiová and Oriskóová (2020) proposed a multi-layer artificial neural network based on 663 Slovak companies from five industries from 2014 to 2017. Gregova et al. (2020) found that neural networks have better model performance based on comparing three methods: logistic regression, random forest, and neural network. The Czech research on financial distress prediction is slightly more developed (Vochozka, 2017; 2018) than Slovak research. The author assessed financial distress in the Czech construction using MLP. Tab. 4 compares neural networks from multiple authors from different countries based on selected performance metrics. It was determined that the two best prediction models proposed in this paper achieved similar performance metrics compared to other models. However, the offered models are based on a sample several times larger than the models from previous research, so the results are more relevant.

Conclusions

This paper provides a set of models for early warning of potential financial problems in real-time for all Slovak industries. MLP and RBF achieved comparable results to the Kohonen map. Boosting and bagging techniques were applied to these neural networks. The results show that these combined models increase the predictive power of individual models. Finally, it was demonstrated that MLP networks achieve higher overall accuracy than RBF. However, the boosting RBF model achieves the highest predictive ability in identifying the non-prosperity of Slovak companies. This model can be applied to small and medium-sized enterprises from various industries. Financial management was optimised with machine learning techniques; these findings help financiers and managers create credit policies after programming them. The prediction model applies financial indicators with artificial intelligence to achieve high efficiency and accuracy in assessing financial conditions. The paper proposes a machine learning approach as a more appropriate methodology than traditional techniques for predicting a company's future financial problems. This approach improves managerial skills to understand complicated aspects and make better decisions. Lenders can use these models for estimating potential financial risks. On the other hand, investors use the application as a tool for investment decision-making. Finally, the model serves as a tool to maintain long-term sustainability.

Limitations. Various limitations of the conducted research exist. First, the neural network-based prediction model does not reflect the limited market opportunities of companies during the global COVID-19 pandemic and their impact on the entire financial and economic side of corporate governance. Second, the model could not be validated on other samples of companies from Central European countries. One of the disadvantages of neural networks is their difficulty in reproducing the model on other samples. A software application has to be created, with the help of which their application to new cases or whole samples of new cases is possible.

Future research. First, future research may focus on designing a comprehensive universal prediction model for companies in all Central European countries. Second, potential research may be focused on combining multiple neural network approaches as part of ensemble models. These models can improve performance metrics and better classification ability for prosperous and non-prosperous companies. Third, the proposed model can be compared with individual models based on other statistical approaches to reliably determine the corporate financial condition.

The paper highlights that neural network models are suitable for identifying financial distress. Therefore, neural networks help financial managers and stakeholders defend against unfavourable financial situations in decision-making. The presented models develop the existing theoretical approach, awareness, and knowledge of neural networks in risk management, focusing on companies from the Slovak Republic because previous research on predicting financial distress is not very developed in Central Europe. The results help to identify strengths and weaknesses in the company's financial management.

Acknowledgement

This research was financially supported by the Scientific Grant Agency of The Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences — Grant No. 1/0166/20.

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Volume 15 • Issue 3 • 2023

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 17 October 2022
accepted: 10 May 2023

pages: 14-26

Manufacturing equipment retrofitting towards Industry 4.0 standards — a systematic overview of the literature

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ABSTRACT
The main purpose of this paper is a systematic literature review on retrofitting tools, equipment, and infrastructure in the industrial domain. The methods used for the research were a systematic literature review: publication analysis, selection of databases, and appropriate modification of queries in individual databases. Findings were presented using a map of keywords, clusters, and charts. The main result of the conducted research was the identification of the main trends in the retrofitting area. The trends developed within the review can support further research into the direction of retrofitting methods and the factors determining the choice of specific techniques and tools in the digitalisation of manufacturing enterprises.

KEY WORDS
Industry 4.0, retrofitting, Internet of Things, equipment modernisation and adaptation, smart manufacturing

10.2478/emj-2023-0017

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Introduction

Currently, rapid industrial production changes are evident. Guerreiro et al. (2018) pointed out that responding to them determines the survival of industrial companies. On the one hand, there is the development of systems, devices, and techniques called Industry 4.0. This trend drives the exponential growth in various technology uses related to smart manufacturing, data clouds, and big data processing. Data is provided by various types of sensors, many of which belong to the Internet of Things. Keshav Kolla et al. (2022) presented an example of a drill sensorisation

Słowik, M., & Sierocka, H. (2023). Manufacturing equipment retrofitting towards Industry 4.0 standards – a systematic overview of the literature. *Engineering Management in Production and Services, 15*(3), 14-26. doi: 10.2478/emj-2023-0017

that allowed data to be collected and then processed in a data cloud using machine learning techniques (Lins et al., 2018). Predictive maintenance and anomaly detection can be mentioned as solutions for the early detection of undesirable changes in process parameters or machine operation.

On the other hand, currently, entrepreneurs in the manufacturing sector are particularly exposed to such negative phenomena as sudden increases in raw material prices, changes in fuel prices, transport costs, and other occurrences that reduce production profitability. In addition, they have to meet increasingly stringent standards related to greenhouse gas emissions, comply with the principles of sustainability, and address labour shortages. Most important, however, is the continuous drive to increase the productivity and efficiency of industrial plants.

Niemeyer et al. (2020) proposed using techniques described in the first paragraph above, which can reduce the negative effects of the phenomena outlined below. This requires the adaptation of existing machinery fleets and their components, such as CNC machine tools, table drills, and others, to the requirements of smart manufacturing. It is often impossible to replace machines due to the cost of the whole operation. Therefore, the solution is to retrofit machines and equipment. This operation extends the existing capabilities of the machines by adding sensors that allow the monitoring of operating parameters and communication with systems used in industrial environments, such as SCADA, MES, or ERP.

Another important feature of retrofitting is its evolutionary adaptability, by making slight changes to a limited extent at a low cost and time. Such changes allow for gradual adaptation and rapid verification of the correctness and suitability of machine retrofitting and the creation of a required communication infrastructure. Furthermore, retrofitting supports the idea of sustainability by extending the life of machinery and equipment.

This article presents the results of a systematic literature review for retrofitting techniques and technologies (an analysis of the publications, bibliometric evaluation, and classification of the selected publication database). Different research stages were implemented according to Okoli's (2015) and Fisch and Block's (2018) recommendations. The novelty of the publication concerns the realisation of the review and description of the literature related to the field of retrofitting and its classification, as well as the extraction of the main trends presented in the literature.

This publication answers the following questions:

- What components are included in the retrofitting machinery and equipment concept?
- What are the main trends in the application and development of machinery and plant retrofitting?

The article consists of five parts. An introduction includes a description of the techniques and technologies connected to retrofitting. The second part presents the research methods. The third part is a description of the results obtained from the research. The fourth part discusses the results, and the fifth part is the article's summary.

1. What is retrofitting?

Currently, there is a noticeable increase in the implementation of concepts of Industry 4.0 and Smart Manufacturing in various industries (Camarena-Gil et al., 2020). This is linked to the need for the digitalisation of businesses to counteract the disruption of supply chains and optimise production. The technological development increases the availability of sensors, cloud computing, and data storage and processing methods using machine learning and artificial intelligence techniques.

Historically, the retrofitting of machine tools used in the manufacturing industry was obtained by adding numerical scales to conventional machines to allow the precise reading of process parameters for machining workpieces. This enabled partial automation of measurements and increased the quality of machining work. Kang and Suh (1997) referred to an algorithmisation of finding the best machinability for a five-axis machine tool. Modifications of this type allowed for numerical control. Younkin and Hesla (2008) presented the history of the development of currently used machines with CNC control. They have revolutionised industrial production and are now the standard applied in virtually all industries.

1.1. Sensors

Factory or manufacturing plant equipment components cannot always be remotely controlled, monitored, or communicated via an ICT system. Some mechanically and electrically operable components do not have sensors built in by the manufacturer, making it difficult to service them, predict failures and detect anomalies during their operation. Medina and Manera (2017) presented a case study where, by using wireless sensors as the Internet of

Things devices, they added new functionalities to an existing air-conditioning system. As a consequence of the modifications, the current version of the air-conditioning system allows for automatic control of the air conditioners considering outdoor conditions and detection of the people using them, thus saving energy. Kancharla et al. (2021) presented a retrofitting application using three current sensors and three voltage sensors for an induction motor, additionally visualising the measurements using an augmented reality application.

1.2. Clouds

Various data clouds are used to store and exchange data. They are characterised by their versatility and scalability depending on data processing needs. Among other things, the major cloud providers offer dedicated platforms for storing data, performing calculations, or running their applications. Based on Panda et al. (2020), a cloud was used as an integration layer for data received from sensors. In addition, by using the OPC UA protocol, it was possible to manage sensors and use the obtained data in machine learning algorithms. Integrations of sensor devices with the cloud platform were also performed using the MQTT protocol (Panda et al., 2019). Lima et al. (2019), on the other hand, presented an example of using the cloud to process energy usage data from the Internet of Things sensory devices and make it available as a digital twin model to third-party companies.

1.3. Algorithms for data processing

With sensors and data in the cloud, algorithms are required to generate new knowledge from raw data. Hesser and Markert (2019) used artificial neural networks to determine the tool wear of a CNC milling machine from accelerometer data. Another example of the use of neural networks is the assessment and monitoring of spindle conditions presented by Corne et al. (2017). One more example, presented by Pandiyan et al. (2018), is the application of support vector machines (SVMs) and genetic algorithms to analyse data from multiple sensors during the grinding process of an abrasive belt. A comparison of the use of random forests, neural networks and support vector regression (SVR) is presented for tool parameter evaluation (Wu et al., 2017). Measurements of forces and vibrations in three axes and generated sound intensity were used as data. Among data processing algorithms, methods for visualising data in virtual or augmented space can be distinguished. Al-Maeeni et al. (2020) presented the possibility of using HoloLens goggles as navigation support during the machine startup for the end user. Another example of using augmented reality is the retrofitting of an engine in a manufacturing system, described by Kancharla et al. (2021). The collected data is visualised using a dedicated web-based application. On the other hand, Mourtzis et al. (2020) presented a conceptual framework to support decision-making assisted by an online network and based on augmented reality for retrofitting and recycling machinery.

1.4. Industry 4.0

The works presented by Sanghavi et al. (2019) and Olsen and Tomlin (2020) outlined selected features of Industry 4.0, including the communication of machines interconnected through the Internet of Things devices, i.e., sensors, a cloud layer ensuring their integration and appropriate data exchange, machine learning, and artificial intelligence algorithms processing the collected data. An example of using an accelerometer to measure and monitor a CNC machine tool was given by Herwan et al. (2019). The authors used vibration measurements and the development and training of machine learning models to achieve a tool wear detection accuracy of 88 %. A proposal for a reference model and an architecture for implementing Industry 4.0 elements was presented by Pisching et al. (2018). The authors presented a model called RAMI 4.0 — a Reference Architecture Model for Industry 4.0. The subsequent layers of the model are Layer I — hardware, and products, Layer II — data integration and exchange layer, and Layer III — communication and information layer. Layer IV is the functional layer, and Layer V is the business layer. The hierarchical division allows flexible modelling of the Industry 4.0 elements and their simplified implementation. The most advanced example of the technologies included in Industry 4.0 is digital twins. Concepts for their use were presented by Gulewicz (2022).

2. Research methods

This publication uses the method of systematic literature review. In it, successive stages of bibliometric analysis were carried out. Successive stages of the

review have been described in detail in several publications (Torres-Carrión et al., 2018, Xiao & Watson, 2019; Nightingale, 2009; Szpilko & Ejdys, 2022). As a first step, a selection of databases was made. Due to the search for publications in the field of engineering sciences, the topics of publications were limited to those related to manufacturing, industry, the use of sensors, and information technology. This allowed the selection of the three databases described below. The next stage consisted of selecting queries and limiting the cut-off date period to obtain the desired group of results.

The third step was the application of a restriction criterion allowing a reference to recent publications published in English and not withdrawn. The final stage of the study was a bibliometric analysis of the results obtained as a result of the previous steps. The next steps are shown in Fig. 1.

Based on the bibliometric analysis, the most productive countries, organisations, journals and authors were presented. An analysis of the most frequently used keywords was also performed.

The literature review was limited to the following bibliographic databases:

- Web of Science,
- Scopus,
- IEEE Explore.

The bibliometric analysis included publications containing the word "retrofitting" AND machines OR industry OR manufacturing OR device OR equipment OR factory in the title. The restriction to the title of the publication was introduced after a preliminary analysis of searches in all available fields. The next step was to set the appropriate inclusion criteria. Publications published between 2002 and 2022 in English were included in the analysis. Articles, reviews, conference proceedings, and books were submitted for analysis. The corresponding filter phrases for each are shown in Table 1 below.

Table 1 shows the results of the search in the databases. The first search in all possible fields yielded 6436 records in the Web of Science database, 6536 in the Scopus database, and 1316 in the IEEE Xplore database.

Adopting the inclusion criteria yielded 5763, 4729 and 917 records, respectively.

The analysis of the results showed that many of the publications were not related to the field under consideration, which is why the authors decided to limit the search to publications that contain the previ-

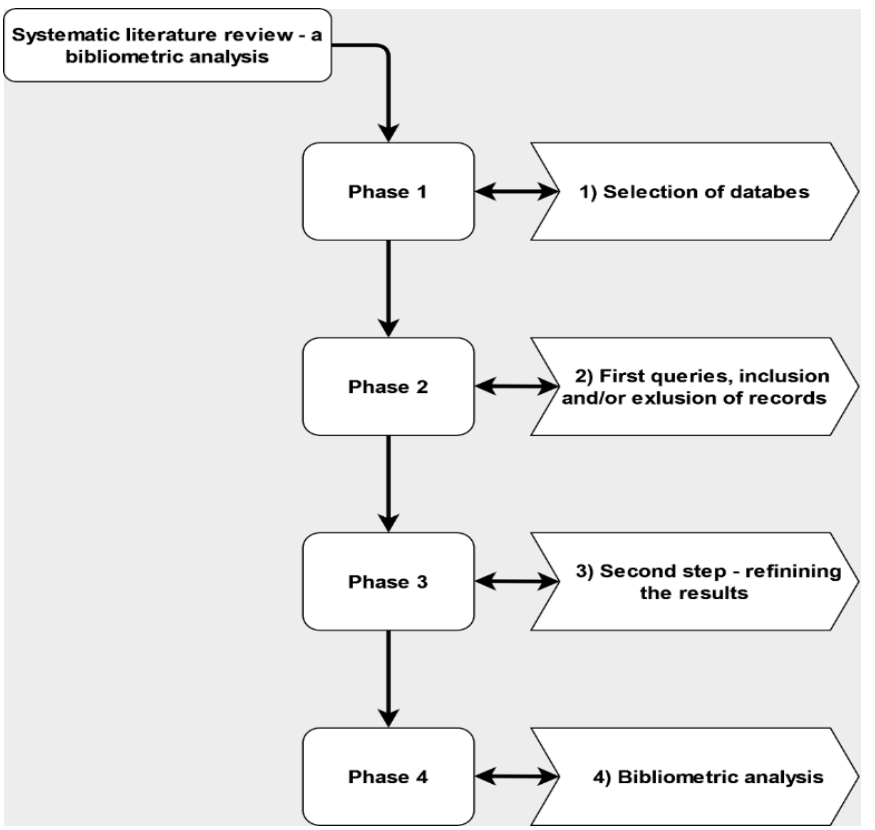

Fig. 1. Scheme of systematic literature review

Tab. 1. Summary of phrases used during the literature review

Phase	Web of Science	Scopus	IEEE Xplore
Research query 1	Analyse Results: retrofitting (All Fields) AND machines OR industry OR manufacturing OR device OR equipment OR factory (All Fields)	TITLE-ABS-KEY (retrofitting) AND TITLE-ABS-KEY (machines OR industry OR manufacturing OR device OR equipment OR factory)	"All Metadata":retrofitting AND ("All Metadata":machine OR "All Metadata":industry OR "All Metadata":manufacturing OR "All Metadata":device OR "All Metadata":equipment OR "All Metadata":factory)
Number of articles without inclusion criteria	6436	6536	1316
Number of articles with inclusion criteria	5763	4729	917
Research query 2	Analyse Results: retrofitting (Title) AND machines OR industry OR manufacturing OR device OR equipment OR factory (Title)	TITLE (retrofitting) AND TITLE (machines OR industry OR manufacturing OR device OR equipment OR factory)	„Document Title":retrofitting) AND („Document Title":machines OR „Document Title":industry OR „Document Title":manufacturing OR „Document Title":device OR „Document Title":equipment OR „Document Title":factory)
Number of articles without inclusion criteria	274	152	45
Number of articles with inclusion criteria	205	112	38

ously mentioned phrases in the title of the article. The results of the analysis are also presented in Table 1. Search queries only in the title of publications showed 274 records in the Web of Science database, 152 records in the Scopus database and 45 records in the IEEE Xplore database. After applying the inclusion criteria, the filtering results gave 205, 111 and 38 records, respectively.

Subsequently, one summary file was created containing 354 records after removing duplicates and incomplete records. The final file contains 266 records. In 2022, 12 publications were registered in the Scopus database, ten publications in the Web of Science database, and four publications in the IEEE Xplore database.

The article shows the changing interest in the topic over the years and identifies the main research areas, the most productive countries, journals, organisations, authors and the most frequently cited articles. The results of the analysis are presented in graphical form. Maps of keywords and their co-occurrences were drawn up. The co-occurrence of keywords was made based on a file downloaded from the Scopus database using VOSviewer software and the authors' thesaurus file.

3. Research results

Based on the results obtained from the Scopus database, keywords from publications were divided into clusters, shown in Table 2 and visualised in Fig. 2. As a result, the authors obtained five clusters containing 13 to four elements. The first and biggest cluster contains keywords connected mainly with the benefits of retrofitting.

The second includes different outcomes from upgrading machines that are pushing the industry towards smart manufacturing, data visualisation and, in general, Industry 4.0. The third contains different types of systems and subsystems used in the industry, e.g., computer control systems, embedded systems and computer-aided design techniques. The fourth cluster has keywords linked with commerce, industry in general and the state of the art solutions. The fifth cluster includes such general concepts as automation and robotics, connected with the industry's transformation towards Industry 4.0.

Fig. 3 shows the change in the number of publications related to retrofitting from 2002 to 2022. In blue, the graph shows the number of publications from the Web of Science database; the pattern of publications since 2015 is particularly evident. This correlates with the development of cloud technologies and the wide availability of techniques related to large data sets (big data). In other charts, the increase in the number of publications since 2015 is also evident. Fig. 4, on the other hand, shows the share of different types of publications in each database.

Fig. 4 shows a breakdown by the publication type, i.e., articles in scientific journals, conference materials and others. The vast majority of publica-

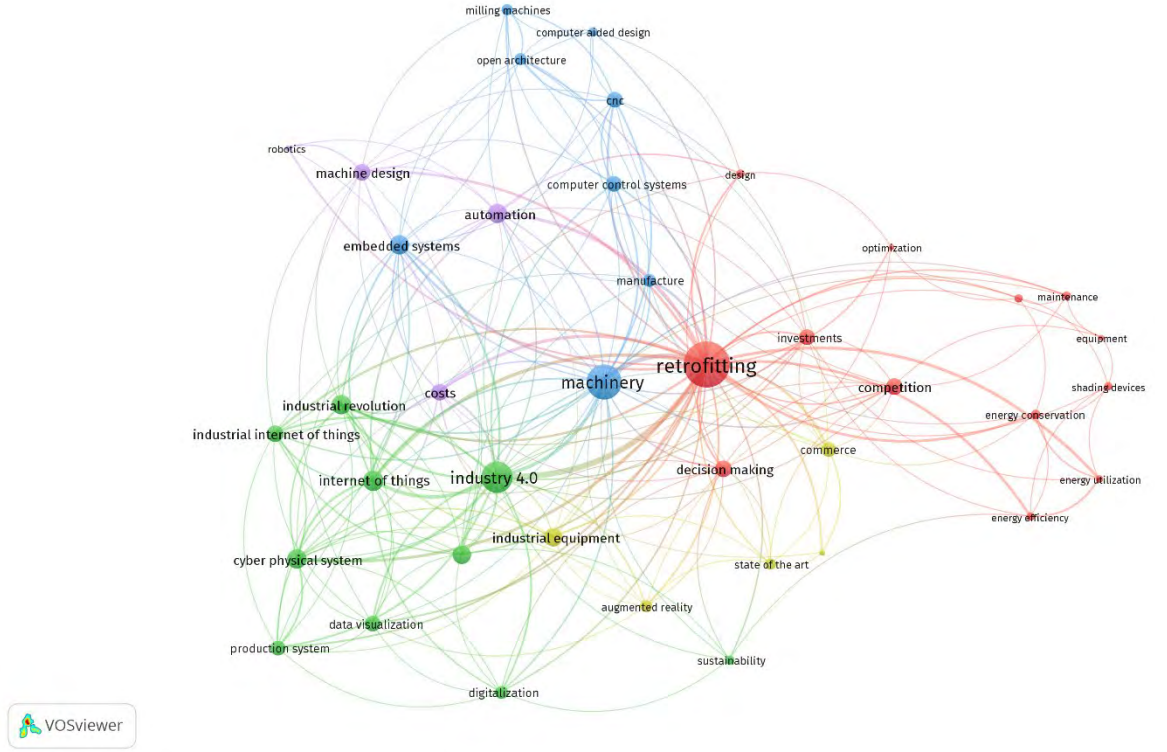

Fig. 2. Map of keyword associations and clusters

Tab. 2. Breakdown of keywords into clusters generated with VoSViewer

CLUSTER 1 (13 ITEMS) PROCESSES	CLUSTER 2 (10 ITEMS) SYSTEMS AND CONCEPTS	CLUSTER 3 (8 ITEMS) HARDWARE AND INFRASTRUCTURE
competition decision-making design energy conservation energy efficiency energy utilisation equipment investments retrofitting maintenance optimisation performance assessment shading devices	cyber-physical system data visualisation digitalisation industrial Internet of Things industrial revolution Industry 4.0 Internet of Things sustainability smart retrofitting production system	CNC computer-aided design computer-control systems embedded systems machinery manufacture milling machines open architecture
CLUSTER 4 (5 ITEMS) INDUSTRY	**CLUSTER 5 (4 ITEMS) AUTOMATION AND ROBOTICS**	
commerce augmented reality industrial equipment industry state-of-the-art	automation costs machine design robotics	

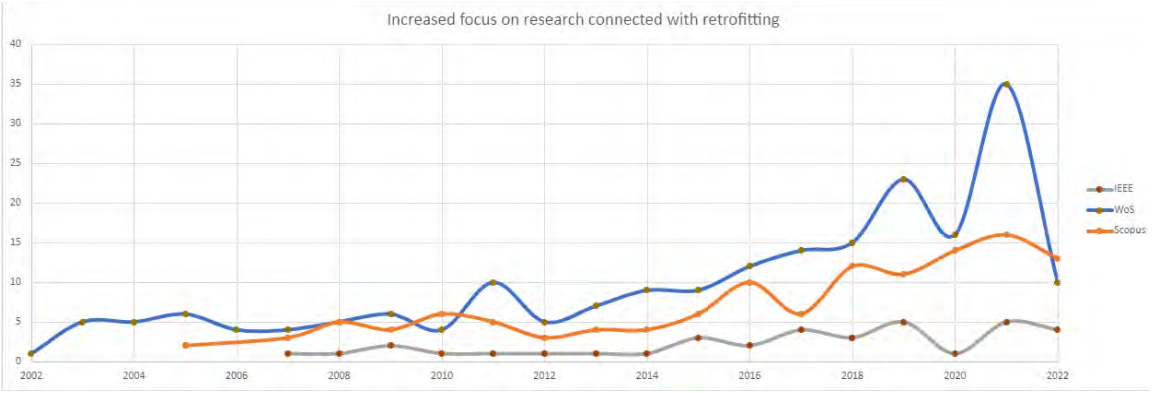

Fig. 3. Chart of the growing number of publications in the area of retrofitting

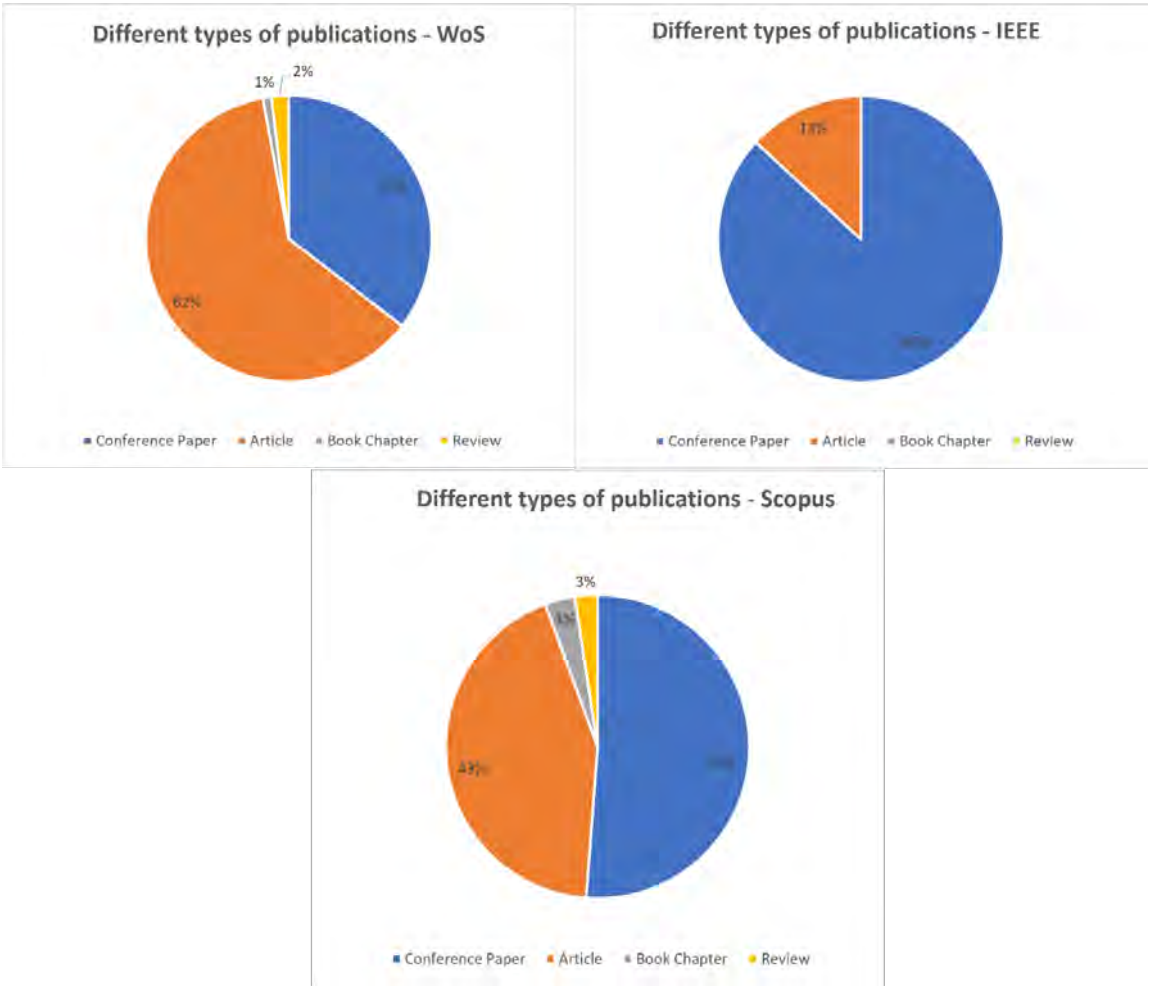

Fig. 4. Different types of publications for each database

tions were presented at scientific conferences, which indicates the topicality of the subject. The IEEE database shows that publications presented at scientific conferences account for as much as 87 % of all publications.

The smallest portion of publications in all databases are chapters in books.

Based on the analysis, a cloud of the most frequently occurring keywords was created. It can be noted that the resulting cloud contains phrases related to Industry 4.0, digitalisation, machines, and optimisation.

Table 3 summarises data on the most prolific countries, journals and organisations in terms of

Fig. 5. Most occurring key words

Tab. 3. Most productive countries, organisations and journals

No.	Item	Np	%oft	Average citation count		
				WoS	Scopus	IEEE Xplore
	Most productive countries					
1	United States	36	13,5	15,1	10,9	0,67
2	Italy	29	10,9	9,0	8,7	4,0
3	United Kingdom	18	6,8	12,4	15,0	1,0
4	China	17	6,4	23,4	37,1	N/A
5	Germany	16	6,0	8,9	8,5	5,3
6	Iran	9	3,4	5,9	9,7	N/A
7	Taiwan	9	3,4	10,1	3,7	2,0
8	Brazil	8	3,0	14,0	33,8	9,6
9	South Korea	7	2,6	3,7	N/A	4,0
10	Spain	7	2,6	6,4	7,6	3,7
	Most productive organisations					
1	Fraunhofer gesellschaft	5	1,9	13,8	12,3	6,0
2	ETH Zurich	4	1,5	7,8	16,0	7,0
3	University of California system	4	1,5	2,8	N/A	N/A
4	University of Manchester	4	1,5	6,3	2	N/A
5	Aalto university	3	1,1	5,3	N/A	N/A
6	Consiglio nazionale delle ricerche CNR	3	1,1	8,0	0	N/A
7	Hanyang university	3	1,1	7,7	N/A	N/A
8	Industrial technology research institute Taiwan	3	1,1	1,7	N/A	2,0
9	Marche polytechnic university	3	1,1	5,3	N/A	N/A
10	University of California Berkeley	3	1,1	3,7	N/A	N/A
	Most productive journals					
1	IEEE Access	37	13,9	7,5	2,0	2,9
2	Engineering structures	9	3,4	10,8	N/A	N/A
3	Sustainability	8	3,0	9,3	7,8	N/A
4	Energies	5	1,9	3,6	6	N/A
5	Applied energy	4	1,5	20,3	N/A	N/A
6	Bulletin of earthquake engineering	4	1,5	6,5	N/A	N/A
7	Earthquake engineering structural dynamics	4	1,5	10,3	9,5	N/A
8	Advanced materials research	3	1,1	0,3	1,0	N/A
9	Energy and buildings	3	1,1	47,3	N/A	N/A
10	Journal of cleaner production	3	1,1	13,3	12,0	N/A

publishing. The United States (36 publications), Italy (29 publications) and the United Kingdom (18 publications) stand out with the highest numbers of publications over the analysed years. Given the most productive institutions, the largest number of publications came from Fraunhofer-Gesellschaft (five articles) and ETH Zurich and the University of California submitted four publications each. Regarding the most productive journals, the largest number of publications was published by IEEE Access (37 publications), Engineering structures (nine publications) and Sustainability (eight publications).

4. Discussion of the results

The systematic literature review presents the components of retrofitting in the domain of machinery and equipment. The review of publications confirmed the proposed division of the elements of retrofitting machines and devices into three components, i.e., sensory elements, clouds and the Internet of Things devices as communication elements, and artificial intelligence algorithms and machine learning techniques for making conclusions based on collected data.

Also, the authors identified five thematic fields of academic publications connected with retrofitting, shown in Fig. 2, i.e., (1) Processes, (2) Systems and Concepts, (3) Hardware and Infrastructure, (4) Industry, and (5) Automation and Robotics. The identified fields are also mutually connected, which shows their links on different levels. The thematic fields are presented in Fig. 6.

The first field — Processes — connects retrofitting as a process with terms and different ways of process optimisation. The main term — retrofitting — impacts different areas of upgrading the ability to monitor equipment and make processes more intelligent. This cluster consists of thirteen terms, mainly connected with creating additional value through such processes as decision-making, design, maintenance, optimisation and performance assessment. Retrofitting as a general proposal to upgrade a machine tool to Industry 4.0 standards is presented in the paper by Arjoni et al. (2017). The proposed methodology describes in detail the functional requirements, design parameters, data model and system architecture for retrofitting CNC machines, enabling engineers to create designs tailored to real industries. In contrast, a description of the framework process for transitioning an existing factory to Indus-

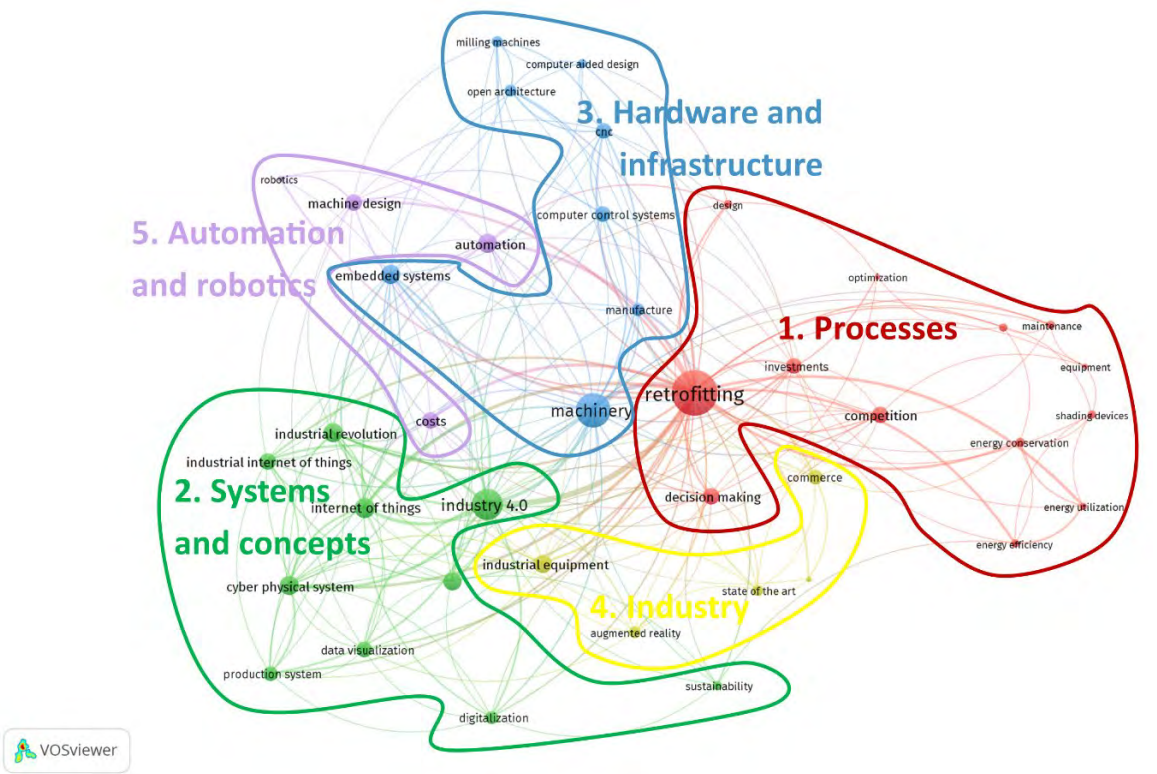

Fig. 6. Co-occurrence map with thematic fields connected with retrofitting

try 4.0 was presented by Carlo et al. (2021). This group also contains phrases connected with energy conservation, utilisation or increasing energy efficiency. This topic was considered in the paper by Lima et al. (2019).

The second field — Systems and Concepts — includes ten phrases connected with the (industrial) Internet of Things, digitalisation, production system and Industry 4.0 in general. This field describes methods for digitalisation and retrofitting of different components of production systems. Tantscher and Mayer (2022) proposed a procedure model for Digital Retrofitting, which is the result of analysing and grouping existing process models. This fills a gap in existing procedure models, which either address very general aspects or focus too little on digital retrofitting as holistic and multidimensional. A holistic approach to the problem of retrofitting allowed Ilari et al. (2021) to present a framework for assessing the sustainability of implementing a smart retrofitting process for old machines as an alternative to replacing them with new ones. Holistic development of the next stages of retrofitting machinery, equipment and processes was presented by Pisching et al. (2018).

The third field — Hardware and Infrastructure — contains eight phrases presenting the development of retrofitting methods, mainly technical solutions, connected with computer-aided design and control systems, embedded systems and their applications in manufacturing. Sridevi et al. (2015) presented a methodology for modernising CNC machines. Quatrano et al. (2017) described the development of a controller and open-loop control system to reuse an existing CNC machine to perform simple manufacturing operations. Panda et al. (2019) proposed a method for quality control by identifying the impact of process parameters and proposed architecture for retrofitting existing machines in the food industry area. Their solution involves implementing a hardware device capable of collecting a huge amount of process data and integrating it with a cloud-based platform for further analysis.

The fourth field — Industry — includes five phrases, such as commerce, augmented reality, industrial equipment, industry and state-of-the-art. The description concerns new component retrofitting technologies, such as cloud data, augmented or virtual reality, and their application to retrofitting machines and equipment. Xie et al. (2019) explored the potential of using Big Data Analytics (BDA) in smart cities. The paper examines how the interconnectedness of the Internet of Things, machine-to-machine communication, Big Data and Smart Cities can help anticipate and meet the needs of retrofitting projects. Another example of a publication describing the use of selected components of retrofitting is the description of a proposal for an architecture for retrofitting an older machine with external sensors presented by Keshav Kolla et al. (2022). Sensors are used to collect data and feed databases into the cloud for analysis and monitoring. In contrast, an example of using artificial neural networks to assess tool wear was described by Hesser and Markert (2019). Using augmented reality as a method for retrofitting a production machine was presented by Al-Maeeni et al. (2020).

The fifth field — Automation and Robotics — has four phrases: automation, costs, machine design and robotics. Arjoni et al. (2017) presented the retrofitting of automation and robotics components of manufacturing lines. Retrofitting can be beneficial in the context of upgrade costs by upgrading instead of exchanging devices. An example is retrofitting for data integration in the cloud, presented by Panda et al. (2020).

The fields described above intersect at phrases with the largest connection numbers. The main connection is at the centre of Fig. 6, between the terms retrofitting (1. Processes), machinery (3. Hardware and Infrastructure), Industry 4.0 (2. Systems and Concepts), industrial equipment (4. Industry) and automation (5. Automation and Robotics). The above connection can be the result of the interdisciplinary character of machine retrofitting used in the industry, especially in the transformation of current manufacturing elements to the standards of interconnected components of the Industry 4.0 concept. The literature review had no publications on the exact cost calculation of retrofitting and comparing it with the cost of purchasing a new machine that meets specific requirements. There were also no publications that would deal with the retrofitting of the entire production line and its adaptation to Industry 4.0. Also, there were no articles showing the quality of elements made on machines after retrofitting and new machines.

Conclusions

In this publication, a systematic literature review was carried out on retrofitting machinery and equipment in the manufacturing domain. The following steps were conducted: analysis of publications, selec-

tion of databases, appropriate modification of queries in individual databases, and presentation of results. There is an evident increase in interest in the retrofitti¬¬¬¬ng machinery and equipment, which is related to the desire for the implementation of techniques and technologies that enable the implementation of elements of Industry 4.0 in industrial plants.

The research allowed for identifying five research fields in analysed publications. The first, "processes", is connected with processes that are key components of retrofitting or could benefit from it. The second, "systems and concepts", describes different methods for digitalisation and retrofitting of various elements of production systems and manufacturing lines. The third, "hardware and infrastructure", includes mainly technical solutions connected with specific applications and implementations, e.g., embedded systems and their applications in the manufacturing or CNC-controlled machines. The fourth, "industry", contains different general component horizontal technologies of retrofitting, such as cloud data, augmented or virtual reality, among others, and their application to retrofitting machines and equipment. Lastly, the fifth, "automation and robotics", includes phrases connected with upgrading current automation and robotics to the standards of Industry 4.0. Additionally, the intersections and connections between fields were described using conclusions on possible reasons for connections between them, i.e., the interdisciplinary and multidimensional character of retrofitting. With the growth of artificial intelligence and general artificial intelligence, a higher impact of AI-related technologies on retrofitting is foreseen. Artificial intelligence will make the retrofitting process easier and faster. A few examples of the possible use are anomaly detection, sensor data classification or predictive maintenance. These technologies will optimise production, reduce downtime, increase predictability and prevent downtime. The new use of technology will enhance the quality of production processes, facilitate the retrofitting of machinery, and allow it to adapt smoothly to Industry 4.0.

A systematic literature review and the identified trends helped answer the two research questions posed at the beginning of the paper. Among the components of the techniques and technologies included in the retrofitting of machines and devices, a layer of sensory and communication elements can be distinguished, often integrated into the form of the Internet of Things devices. Another is a data cloud, enabling its storage and mediating its exchange. The last layer is artificial intelligence algorithms and machine learning techniques enabling automated inference based on processed data. The answer to the second question is presented in the fourth chapter, identifying the five thematic fields of publications in the area of machinery and equipment retrofitting.

The research limitations were related to using three bibliometric databases (Web of Science, Scopus and IEEE Explore) and choosing the scope of retrofitting connected with the manufacturing industry.

The next research stages will be to further divide and analyse retrofitting in terms of the adaptation of techniques and technologies and the progressive digitisation and digitalisation of manufacturing enterprises.

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sciendo

received: 15 November 2022
accepted: 15 May 2023

pages: 27-41

Multi-skilled workforce scheduling with training and welfare considerations

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ABSTRACT
Flexibility in workforce scheduling in services is necessary to reduce the impact of demand uncertainty, absenteeism, and desertion while maintaining high service levels. This paper studies the workforce scheduling problem, including multiple skill accumulation, training, and welfare, as well as flexibility for employees and the company. All these elements are modelled and included in a mixed-integer linear programming (MILP) model that maximises their accumulated skill level. A real case study based on the scheduling of lab assistants to laboratory practices at a university in Colombia is used to generate numerical experiments. Different experiments were conducted, and the results show that the level of skill achieved is highly sensitive to the number of assistants and the number of allocations. The experiments also showed that, while keeping the same number of lab assistants, it is possible to include flexibility and welfare constraints. Finally, the proposed model can generate schedules that achieve high levels of skills and meet the different constraints of the model, including balance, accumulation, demand and welfare.

KEY WORDS
flexibility, multiskilling, workforce scheduling, training, optimisation

10.2478/emj-2023-0018

Introduction

A key feature of the current economy is the rapid growth of the service sector, which is labour-intensive, e.g., hospitals, airlines, call centres, education centres, restaurants, etc. In the long term, companies aim to find the right balance between using as little labour as possible while maintaining a high level of service. However, in the short term, the levels of hired staff are difficult to adjust; therefore, management efforts are focused on the efficient assignment of shifts and activities to each employee (Cuevas et al., 2016). In addition, qualitative aspects should be considered,

Peña, D. A., Osorio, A. F., Orejuela, J. P., & Idarraga, J. C. (2023). Multi-skilled workforce scheduling with training and welfare considerations. *Engineering Management in Production and Services, 15*(3), 27-41. doi: 10.2478/emj-2023-0018

such as the welfare, happiness and equity of employees, as well as rules and regulations in each country. These aspects impose strong restrictions on employee allocation, making the problem attractive from an academic point of view (Ağralı et al., 2017). Furthermore, the variability and seasonality of demand are inherent characteristics of many types of services, generating the need to adjust the number of employees accordingly (Henao et al., 2016).

However, the use of labour scheduling to reduce overstaffing and understaffing in the service industry is often undermined by a lack of flexibility due to the exclusive use of specialised employees (Henao et al., 2015). Therefore, training plans must be considered and included in the labour schedule. Multiskilled workers not only add flexibility at the moment of planning but also help to reduce the negative effects of demand uncertainty and absenteeism (Henao et al., 2016). Developing and accumulating employee skills through a training plan can also improve employee satisfaction, as it can be seen as professional growth.

It is common for labour-intensive companies to face situations where employees are dissatisfied with their shift schedules, either due to the allocation of time slots or imbalances in workload compared to other workers. In the case of companies, there are difficulties in building shift schedules to cope with increased demand or cases of absenteeism. These difficulties are caused by the lack of flexibility of employees to perform various tasks within the company, or the company does not have the time or resources to train staff or hire more people. Training and scheduling are not commonly considered simultaneously. This can lead to situations such as:

- An imbalance in the time and number of activities performed by employees leads to difficulties in the work climate and, in some cases, costs associated with overtime.
- Training is not aligned with the assignment of activities. These two objectives are not addressed simultaneously (assignment of activities and training), which hinders the learning processes of new employees and leads to a concentration of competencies on the part of more experienced employees.
- Imbalance of skills due to the lack of polyvalence of all employees and the concentration of dependence on a few employees.
- Inflexible assignment schemes.
- Probability of underestimating or overestimating the number of employees needed.

To improve the aforementioned situations, this study investigated the workforce scheduling problem, including training and welfare considerations. The most common objective in this type of problem is the minimisation of costs, usually represented in labour costs, while meeting demand. However, the approach in this work is different. While demand must still be satisfied, the objective is to schedule shifts considering such aspects as training. It is important to highlight that the model can be easily adapted to other objective functions, such as minimising costs to achieve certain levels of skills while also meeting demand.

This paper considers the flexibility in services through the inclusion of such aspects as skill accumulation to achieve greater availability of employees to perform different types of tasks. This is achieved through experience gained through the execution of tasks by trainees and the training process by expert personnel (trainers), as well as workload balancing to improve the labour environment. This study refers to two types of flexibility: for companies, by having more qualified personnel available to perform different tasks, and for workers, by being increasingly qualified, it is possible to obtain a more balanced workload and even be available for personal matters.

In the case study addressed in this article, laboratory assistants are assigned to different laboratory practices in a university, where they instruct the students on their correct development. Lab assistants must hold a bachelor's degree in a specific area (chemistry, pharmaceutical chemistry, or biology) as well as a certain level of knowledge to operate specialised equipment, depending on the type of practice. The assistants with the appropriate background and higher skill levels can conduct more lab practices. This feature should be considered at the moment of planning since it can generate flexibility in assigning assistants to several practices in different time slots.

Based on the above elements, it is expected that the development of the methodology will contribute to a practical solution to the problem. This research answers the following questions:

- How to optimise the workforce scheduling in a services sector considering training and welfare considerations?
- Is it possible to improve the skill accumulation of employees while meeting demand?

Therefore, based on the literature review, the contributions of this work to the field of knowledge can be summarised as follows:

- Accumulation of skills when a lab practice is carried out. This accumulation applies to trainers and trainees.
- Consideration of two types of skills: those that improve with training or execution and those that remain invariant.
- Flexibility is included for both the organisation and the employees simultaneously.
- A novel MILP that seeks to improve and level the skills of the lab assistants.

The remainder of the article is organised as follows. Section 2 surveys the literature on Labour Scheduling Problem (LSP), skill accumulation and welfare. Section 3 introduces a MILP model for an LSP with skill accumulation, training, and welfare considerations for predefined time slots. Section 4 defines a case study for lab assistants scheduling to develop practices for the Biology, Chemistry, and Pharmaceutical Chemistry programmes in a university. Section 5 describes the experiments performed to evaluate the assignment of lab practices, skills accumulation, and lab assistant training under different conditions. Section 6 presents the results obtained. Finally, Section 7 submits the conclusions and provides suggestions for further research.

1. Literature review

1.1. LSP

The LSP, also known as the employee scheduling problem and workforce scheduling problem, has been widely studied in operations research since Edie (1954) and Dantzig (1954). Orejuela et al. (2014) defined the LSP as the planning of shifts for employees while satisfying multiple factors, such as the company, employees, legal regulations, and demand requirements. This paper presents the LSP as the problem of assigning employees with different levels of skill to different tasks that require minimum skill levels while satisfying restrictions.

Different aspects of the LSP have been studied. Moreno and Montoya (2016) gave a review on workforce scheduling, classifying papers by the solution tools, the problem objectives, the characteristics of the workforce, the type of shifts, and the demand type. They also classified the workforce as homogeneous or heterogeneous. Homogeneous labour considers that employees have the same level of skill and are the same type of workforce (Al-Yakoob & Sherali, 2008; Jarray, 2009; Ni & Abeledo, 2007; Rocha, Oliveira, & Carravilla, 2014). On the other hand, heterogeneous labour considers different types of employees. In a paper by van der Veen et al. (2015), employees were considered with different skill sets and different contract types, while Goodale and Thompson (2004) considered individual employees with different productivity levels. Karam et al. (2017) developed a model where the skill of the workers is measured by their efficiencies and, thus, affects their execution times of the tasks. More examples of the heterogeneous workforce can be found in other papers (Abdoul Soukour et al., 2013; Cuevas et al., 2016; Yan et al., 2004).

The optimisation objective is another key factor in LSP research. In most industries, costs associated with the workforce represent a considerable proportion of the total costs. This has motivated multiple researchers to develop models minimising these costs. Some of the costs are regular working time cost and overtime cost of internal resources and working time cost of hired external resources (Heimerl & Kolisch, 2010), costs related to different types of activities (Rong & Grunow, 2009), costs of hierarchical workers with different qualifications (Ulusam Seçkiner et al., 2007), fixed and variable costs regarding a minimum of hours worked by the employees (van der Veen et al., 2015).

Regarding the solution strategies, multiple approaches have been taken to solve the LSP. Van der Veen et al. (2015) proposed a MILP model to solve their cost-efficient staffing problem. Huq et al. (2004) and Karam et al. (2017) also proposed a MILP as a solution strategy. However, with large instances, some MILP formulations become impractical solution strategies because of the large computational time needed to find the optimal solution. Because of that, heuristics have become an important and practical option for solving large problems. Petrovic and Vanden Berghe (2012) solved a nurse rostering problem using a metaheuristic and compared it with a case-based reasoning approach.

Goodale and Thompson (2004) compared four individual worker assignment heuristic methods, three of which did not require a computer, and one used a simulated annealing heuristic method. Other heuristic approaches were described by Houghton and Portougal (2005) and Rocha et al. (2014). The first one proposed the use of the stones heuristic, which makes allocation decisions sequentially, while the second developed a constructive heuristic for solving the staff scheduling problem of a glass manufacturing unit.

The LSP with learning effects has received attention in recent years. The complexity of the problem and its nonlinear nature due to the learning curve has made this problem an interesting and relevant subject of research. Bentefouet and Nembhard (2013) described the problem of scheduling heterogeneous workers in a flow line by modelling their performance and learning behaviour. Their objective was to maximise the throughput of the flow line, and they showed how the optimality of this objective depends on the learning and productivity characteristics of the workers. Kim and Nembhard (2013) presented a parallel production system with a heterogeneous workforce in which productivity varies dynamically. They used an exponential learning and forgetting model to represent individual learning and forgetting behaviours of the workforce. De Bruecker et al. (2018) also presented a model considering skill development. They described aircraft maintenance workers with different skills; the workers could be trained for a specific skill if necessary. The solution strategy used is a three-stage mixed integer programming approach to optimise the skill mix and find an optimal training schedule for the workforce to reduce costs. Zabihi et al. (2019) proposed a project scheduling problem in which the efficiency of the workforce depends on the time they spend executing the skill. They presented a mixed integer nonlinear programming model with the exponential learning effect and developed two teaching–learning based optimisation algorithms.

1.2. Welfare LSP

Workforce welfare has been a widely studied LSP characteristic because of its importance in employee productivity and satisfaction. Many authors have tackled this problem by balancing the worker's workload. Rocha et al. (2013) tried to level the working days of multiple worker teams by using an objective function that minimises the maximum number of days each team works. Research by Rojas et al. (2008) minimised the difference between the assigned hours to each employee, thus balancing the working hours of the entire workforce, while Kaplansky and Meisels (2007) considered a lower and upper limit of the number of tasks that each worker can be assigned to in each schedule.

Other authors have proposed employee satisfaction as an optimisation objective to ensure the welfare of the workforce. Al-Yakoob and Sherali (2006) developed a model to assign faculty members to classes considering their preferences regarding specific classes and time slots and proposed a dissatisfaction cost function. Akbari et al. (2013) proposed a mixed integer programming model to maximise employee satisfaction based on their preferences in their shift assignment. Al-Yakoob and Sherali (2007) developed a mixed-integer program that considered the employee preferences for stations, off-days, and shifts (see also Al-Yakoob & Sherali, 2007a, 2008). More examples related to employee satisfaction can be found in other papers (Mac-Vicar et al., 2017; Örmeci et al., 2014).

This investigation addresses a problem of an LSP with heterogeneous employees and activities that require different minimum levels of skill. This paper also considers such aspects as the welfare of the lab assistants and training. This paper differs from the described literature in several aspects. First, the balance of the skills attained is considered an objective; these skills are accumulated as the assistants perform their activities. Secondly, the proposed model identifies the lab assistants that do not meet the minimum level of skill required. These assistants are trained by developing practices together with another assistant with a higher level of skill. This allows skill accumulation through the execution of tasks and training at the same time. Furthermore, the proposed model also considers two skill types, one that improves with the execution of activities or training and other skills that remain unchanged (equal to the starting level). In addition, other elements are also included that contribute to the welfare of the assistants, such as availability, the balance of working hours, and flexible scheduling for assistants who are assigned to night shifts the day before. The problem is formulated as a MILP, which is solved optimally with the help of hierarchy constraints and redundant constraints that allow reducing the search space.

2. Research methods

2.1. MILP model

This section formulates the MILP model for solving an LSP with the accumulation of skill, training, and welfare considerations. The model's sets, parameters, and variables and their corresponding notation are defined:

Sets

$A =$ Lab assistants, indexed by a
$M =$ Months, indexed by m
$S =$ Weeks, indexed by s
$D =$ Days, indexed by d
$F =$ Slots, indexed by f, $f1$ and $f2$
$T =$ Types of lab practices, indexed by t
$P =$ Lab practices, indexed by p
$H =$ Skills, indexed by h

Induced sets

$PR\{d\} =$ Set of practices p that can be made in day d
$SP\{p\} =$ Set of time slots f required for practice p
$WM\ \{m\} =$ Set of weeks s that belong to month m
$DW\{s\} =$ Set of days d that belong to week s
$DWM\{s, m\} =$ Set of days d that belong to week s and month m
$PT\{t\} =$ Set of practices p that belong to the type of practice t
$TP\{p\} =$ Set of type of practice t which practice p belong to
$PSD\{f, d\} =$ Set of practices that take place at slot f in the day d
$PA\{a\} =$ Set of practices that can be made by assistant a
$AP\{p\} =$ Set of lab assistants that are able to make practice p

Model parameters

$ss_f =$ Starting time for slot f, $f \in$ F
$fs_f =$ Finishing time for slot f , $f \in$ F
$ah_{ah} =$ Initial skill level h of the assistant a, $a \in$ A , $h \in$ H
$mh_h =$ Maximum cumulative skill level h, $h \in$ H
$hr_{ht} =$ Minimum required skill h for practice type t, $h \in$ H, $t \in$ T
$comp_{f1,f2} =$ Compatibility between the slot $f1$ and slot $f2$, $f1 \in$ F, $f2 \in$ F
$ph_{ht} =$ Percentage that increases the skill h of an assistant when performing the type of practice t, $t \in$ T, $h \in$ H
$hus =$ Maximum hours per week
$hls =$ Minimum hours per week
$M =$ Large value
$hem =$ Maximum overtime per week
$htl =$ Weekly hours for logistics work of the assistants
$hum =$ Maximum idle scheduled hours
$mp =$ Maximum number of practices that an assistant can make per day
$ahm =$ Skill contribution from practice with highest contribution
$tuf =$ End time of the ending later slot

Decision variables

$Z_a = 1$ if lab assistant a is scheduled to any practice, 0 otherwise, $a \in$ A
$X_{ap} = 1$ if lab assistant a make the practice p, 0 otherwise, $a \in$ A, $p \in$ PA{a}
$Y_{ahp} =$ Cumulative skill level for lab assistant a in skill h during the practice p
$BSA_{ahp} =$ Binary that indicates if the assistant a has been over $-$ enabled in skill h when doing the practice p
$D_{ad} =$ Total hours that lab assistant a is scheduled on day d

IA_{ad} = Entrance time that the lab assistant a has on day d
SA_{ad} = Departure time that the lab assistant a has on day d
EH_{ah} = Cumulative excess of lab assistant a in skill h with the practice p
DH_{ah} = Cumulative deficiency of lab assistant a in skill h with the practice p
HS_{as} = Hours worked by lab assistant a in the week s
ES_{as} = Overtime of lab assistant a in the week s
US_{as} = Number of hours remaining for the lab assistant a to complete the time slot of the week s
$BHES_{as}$ = Binary overtime of lab assistant a in the week s
OS_{as} = Scheduled time of the assistant a in the week s without practices
$HMIN$ = Skill level accumulated by the assistant who accumulated lowest skill level

Objective function

$$\text{Maximise } HMIN \tag{1}$$

The objective function (1) seeks to maximise the lowest accumulated skill for lab assistants in the last practice. This ensures that assistants' skills are levelled at the end of the horizon planning. Moreover, for further academic terms, the allocation will be easier (assuming the same lab assistants) since all of them will be able to attend the practices generating flexibility for the company.

Constraints

$$Y_{ahp} + (1 - Z_a) * ahm * mp * nd \geq HMIN \quad \forall\, a \in A, h \in H, p\ in\ P: p = np \tag{2}$$

$$\sum_{p \in P} X_{ap} \geq Z_a \,\forall\, a \in A \tag{3}$$

$$\sum_{a \in AP} X_{ap} \leq 2 \,\forall\ p \in P \tag{4}$$

$$\sum_{a \in AP} X_{ap} \geq 1 \,\forall\, p \in P \tag{5}$$

$$Y_{ahp} = ah_{ah} * Z_a \quad \forall\, a \in A, h \in H, p\ in\ P: p = 1 \tag{6}$$

$$Y_{ahp} = Y_{ahp-1} + X_{ap-1} * hr_{th} * ph_{ht} \quad \forall\, a \in A, h \in H, p\ in\ P: p > 1, t\ \in TP\{p-1\} \tag{7}$$

$$X_{ap} = 0 \quad \forall\, a \in A, p \in (P\ diff\ PA\{a\}) \tag{8}$$

$$Y_{ahp} + Y_{a2hp} \geq (hr_{th}/2) * (X_{ap} + X_{a2p}) - (2 - (X_{ap} + X_{a2p})) * hr_{th} \,\forall\, a \in A, a2 \in A : a \neq a2\,, h \in H, p \in P, t \in TP\{p\} \tag{9}$$

$$Y_{ahp} \geq hr_{th} * X_{ap} + hr_{th} * \left(1 - \sum_{a3\ \in A} X_{a3p}\right) \quad \forall\, a \in A, \qquad h \in H, p \in P, t \in TP\{p\} \tag{10}$$

$$Y_{ahp} \leq mh_h + BSA_{ahp} * ahm * mp * nd \ \ \forall a \in A, h \in H, p \in P \tag{11}$$

$$mh_h - Y_{ahp} \leq (1 - BSA_{ahp}) * ahm * mp * nd \quad \forall\, a \in A, h \in H, p \in P \tag{12}$$

$$Y_{ahp} = mh_h * Z_a + EH_{ahp} - DH_{ahp} \quad \forall\, a \in A, h \in H, p \in P \tag{13}$$

$$EH_{ahp} \leq BSA_{ahp} * ahm * mp * nd \qquad \forall\, a \in A, h \in H, p \in P \tag{14}$$

$$DH_{ahp} \leq \left(1 - BSA_{ahp}\right) * mh_h \qquad \forall\, a \in A, h \in H, p \in P \tag{15}$$

$$\sum_{p\ \in \left((PSD\{f1,d\} \cup PSD\{f2,d\}) \cap PA\{a\}\right)} X_{ap} * (1 - COMP_{f1,f2}) \leq 1 \ \ \forall\, a \in A, d \in D, (f1, f2) \in F \tag{16}$$

$$IA_{ad} \leq X_{ap} * ss_f + \left(1 - X_{ap}\right) * tuf \ \ \forall\, a \in A, d \in D, p \in PR\{d\}, f \in SP\{p\} \tag{17}$$

$$SA_{ad} \geq X_{ap} * fs_f \quad \forall\, a \in A, d \in D, p \in PR\{d\}, f \in SP\{p\} \tag{18}$$

$$tuf * \sum_{p2 \in PSD\{d\}:\, p2<p} X_{ap2} + IA_{ad} \geq X_{ap} * ss_f \;\forall\, a \in A, d \in D, p \in PR\{d\}, f \in SP\{p\} \tag{19}$$

$$-tuf * \sum_{p2 \in PSD\{d\}:\, p2>p} X_{ap2} + SA_{ad} \leq X_{ap} * fs_f + \left(1 - X_{ap}\right) * tuf \quad \forall\, a \in A, d \in D, p \in PR\{d\}, f \in SP\{p\} \tag{20}$$

$$SA_{ad} \leq Z_a * tuf \quad \forall\, a \in A, d \in D \tag{21}$$

$$IA_{ad} \leq Z_a * tuf \quad \forall\, a \in A, d \in D \tag{22}$$

$$SA_{ad} \leq \sum_{p \in PR\{d\}} X_{ap} * tuf \quad \forall\, a \in A, d \in D \tag{23}$$

$$IA_{ad} \leq \sum_{p \in PR\{d\}} X_{ap} * M \quad \forall\, a \in A, d \in D \tag{24}$$

$$D_{ad} = SA_{ad} - IA_{ad} \quad \forall\, a \in A, d \in D \tag{25}$$

$$\sum_{d \in DW\{s\}} D_{ad} = HS_{as} \quad \forall\, a \in A, s \in S \tag{26}$$

$$HS_{as} = hus + ES_{as} - US_{as} \quad \forall\, a \in A, s \in S \tag{27}$$

$$HS_{as} \leq hus + BHES_{as} * hem \quad \forall\, a \in A, s \in S \tag{28}$$

$$ES_{as} \leq BHES_{as} * hem \quad \forall\, a \in A, s \in S \tag{29}$$

$$US_{as} \leq (1 - BHES_{as}) * hus \quad \forall\, a \in A, s \in S \tag{30}$$

$$hls \leq HS_{as} \leq hus \quad \forall\, a \in A, s \in S \tag{31}$$

$$OS_{as} = HS_{as} - \sum_{d \in DW\{s\}} \sum_{f \in F, p \in PSD\{f,d\}} \left(fs_f - ss_f\right) * X_{ap} \quad \forall\, a \in A, s \in S \tag{32}$$

$$htl \leq OS_{as} \leq hum \quad \forall\, a \in A, s \in S \tag{33}$$

$$Z_a, X_{ap}, BSA_{ahp}, BHES_{as} \in \{0, 1\} \tag{34}$$

$$D_{ad}, IA_{ad}, SA_{ad} \in \mathbb{Z}^+ \tag{35}$$

$$Y_{ahp}, EH_{ah}, DH_{ah}, HS_{as}, ES_{as}, US_{as}, OS_{as}, HMIN \in \mathbb{R}^+ \tag{36}$$

Constraint (2) linearises the maximin function, while constraint (3) ensures that every scheduled assistant must be assigned to practice. Constraints (4) and (5) set the upper and lower limits of assistants per practice, respectively. Constraints (6) and (7) control the accumulation of skill, while constraint (8) manages the assistants who are unable to perform certain practices. Constraints (9) and (10) guarantee the minimum skill level of the assistants assigned to practices. Constraints (11)–(15) capture the excess of skill acquired by the lab assistants. Constraint (16) prevents overlapping in the assignment of assistants. Constraints (17)–(25) determine the duration of time for which an assistant is scheduled in one day, while constraint (26) consolidates the weekly hours in which an assistant is scheduled. Constraints (27)–(30) define and limit overtime and missing hours per assistant per week, and constraint (31) defines the limits for the weekly working hours of the assistants. Constraints (32) and (33) define and limit the scheduled hours with no assigned practices that the assistants have per week. Finally, constraints (34)–(36) define the domains for the decision variables.

The following constraints (37) (39) have been added to ensure hierarchy in the assignment of practices by days and slots:

$$\sum_{a \in A\{p-1\}} X_{ap-1} \geq X_{a1p} \quad \forall\, p \in P: p > 1, a1 \in AP\{p\} \tag{37}$$

$$\sum_{a \in A\{p-1\}} X_{ap} * na \geq X_{a2p2} \quad \forall\, d \in D, f \in F, p \in PSD\{f,d\}, p2 \in PSD\{f,d+1\}: d < nd, a2 \in AP\{p2\} \tag{38}$$

$$BSA_{ahp} \leq BSA_{ahp+1} \quad \forall\, h \in H, p \in P: p < np, a \in AP\{p\} \tag{39}$$

One of the key aspects of the model is represented in constraints (9) and (10). These constraints allow the model to allocate a lab practice to an assistant while, at the same time, another lab assistant is being trained. Furthermore, constraints (6) and (7) compute the accumulation of skills every time an activity is performed, either for the one executing party (the trainer) or the one receiving the training (trainee). Finally, constraint (8) synthesises two additional contributions of the model. On the one hand, it guarantees flexibility for lab assistants since they can previously define the set of practices they cannot perform due to personal schedules. On the other hand, this constraint also allows to control the skills that are not cumulative, forbidding the allocation of assistants who do not meet the requirement, such as the academic background. Regarding the welfare of the employees, constraint (16) considers that if the employees have been allocated to practices on the night shift the previous day; they cannot be assigned to practices on the morning shift.

2.2. Case study

The case study used in this paper was conducted in the laboratories of a university in Colombia, where different types of lab practices are developed for the biology, chemistry and pharmaceutical chemistry programmes. In order to develop these lab practices, it is necessary to schedule lab assistants in different predefined time slots for each day. Laboratory assistants must have specifics academic bachelor's degrees and a certain skill level to handle specialised laboratory equipment, depending on the practice type. To

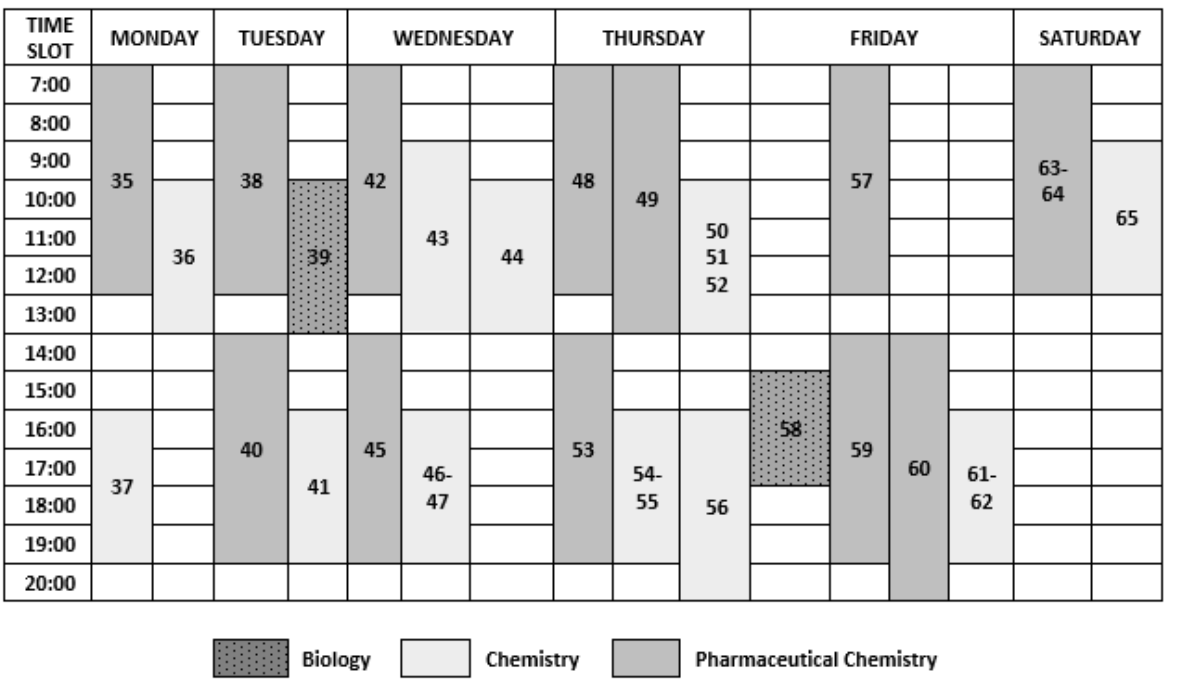

Fig. 1. Example of a weekly schedule for the laboratory practices

be trained in these skills, assistants must be allocated with another assistant to ensure the required skill level.

The scheduling horizon is one academic term (18 weeks, 80 days), during which the university develops 358 lab practices corresponding to 32 types in 18 predefined time slots. For the case study, eight lab assistants with different academic backgrounds were considered: five were chemists, one was a biologist, one was a pharmaceutical chemist, and one was a pharmaceutical chemistry student. Each lab assistant has an initial skill level in handling equipment related to their academic background. Fig. 1 presents an example of a weekly schedule for lab practices. Lab assistants must then be allocated to support the development of each practice. It can be observed, e.g., that for Friday, it is necessary to allocate assistants with three different bachelor's degrees. However, it can also be seen that in the same week, the workload for pharmaceutical chemistry and chemistry practices is higher than for biology, and this situation can change weekly. Moreover, some practices overlap in the same time slot, e.g., practices 59 to 62. Finally, the duration of the time slots is variable, as well as their starting times, generating a total of 18 different time slots.

3. Experiments

Several experiments have been designed to explore and exploit different uses of the proposed model. Some of these experiments require modifications in the objective functions and constraints. The defined experiments to be analysed are presented below.

3.1. Experiment 1. Number of employees vs minimum level of skill

This case explores the relationship between the number of lab assistants and the minimum skill level achieved in the last practice. This experiment represents the initial configuration of the model. Additionally, the following constraint is also introduced to experiment with the maximum number of lab assistants to be programmed. The parameter nap represents the maximum number of lab assistants.

$$\sum_{a \in AP} Z_a = nap \tag{40}$$

Where nap = 6, 7, 8, these values correspond to experiments 1.1, 1.2 and 1.3, respectively. It was found that the problem was infeasible below 6 lab assistants.

3.2. Experiment 2. All the lab assistants are able to make all the practices

This case aims to allow all lab assistants to perform any lab practice. In other words, this experiment is interesting since it allows for the exploration of the minimum number of lab assistants required to serve the current instance under the assumption that all of them meet the skill requirements for all the practices.

The modifications for this case are not in the formulation. Instead, the parameters PA_a and AP_p in the data instance are modified to allow all lab assistants to perform all the practices.

3.3. Experiment 3. Minimising the number of lab assistants and allocations considering a minimum level of skill

This experiment is designed to study several objective functions while achieving a minimum level of skill. The objective functions, as well as the changes introduced, are presented below. To organise the changes, this case is subdivided into experiments 3.1, 3.2, and 3.3. First, in experiment 3.1, the objective function is modified by minimising the number of lab assistants (same as equation (40)) but ensuring a minimum level of ability for all the assistants. To do this, constraint (2) is modified as follows:

$$Y_{ahp} + (1 - Z_a) * ahm * mp * nd \geq 1 \quad \forall\, a \in A, h \in H, p \in P: p = np \tag{41}$$

Second, in 3.2, the same constraint is kept, but the objective function is modified. This allows for finding the minimum number of allocations to ensure the minimum skill level. The objective function is then modified as follows:

$$\text{Minimise} \sum_{a \in A, p \in P} X_{ap} \tag{42}$$

Finally, in 3.3, a weighted objective function is defined that considers both the number of lab assistants and the number of allocations. Some normalisation parameters are used to make the magnitudes similar. The new objective function is presented in equation (43).

$$Minimise \sum_{a \in A, p \in P} X_{ap} + \sum_{a \in A} W * Z_a \quad (43)$$

Where W is a normalisation factor for the number of lab assistants.

4. Research results and discussion

4.1. Allocation of practices

Lab practices are an important part of education; therefore, the allocation of practices to assistants is an important decision to develop processes correctly. Figs. 2, 3 and 4 show the results of the number of practices assigned to each assistant in each experiment, respectively. In experiments 1 and 2, the objective function aimed to balance the workload of the assistants, while in experiment 3, the main target was to minimise the number of workers and allocations and the minimum of skill that the assistants had to accumulate at the end of the time horizon was set very low, which led to a more unbalanced allocation between the lab assistants.

The number of assigned practices to the assistants depends on the number of available assistants to be

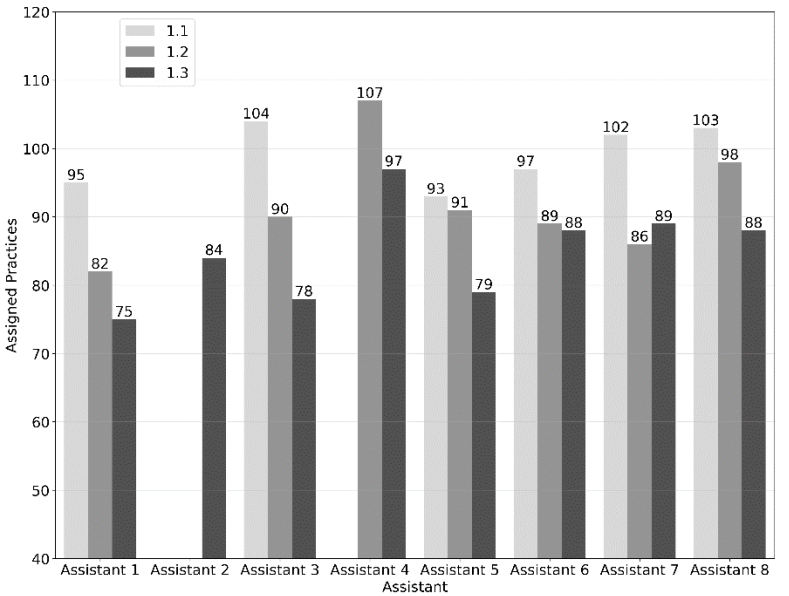

Fig. 2. Assigned practices to the assistants in experiment 1

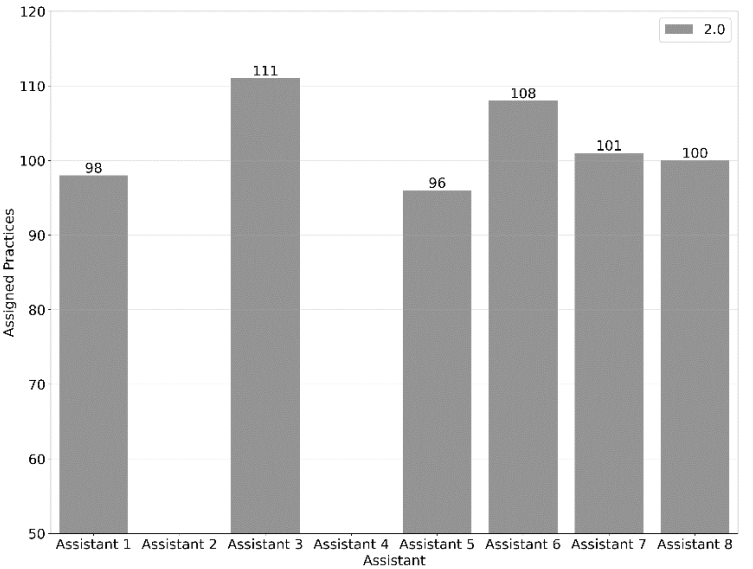

Fig. 3. Assigned practices to the assistants in experiment 2

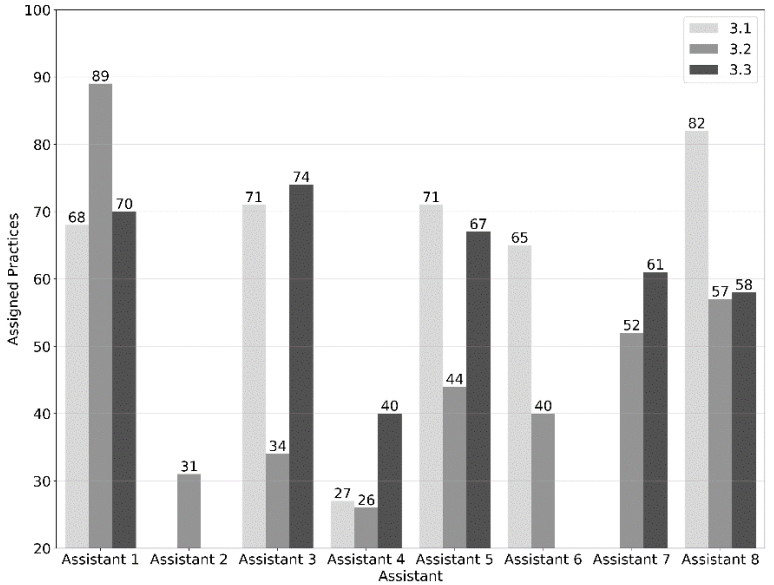

Fig. 4. Assigned practices to the assistants in experiment 3

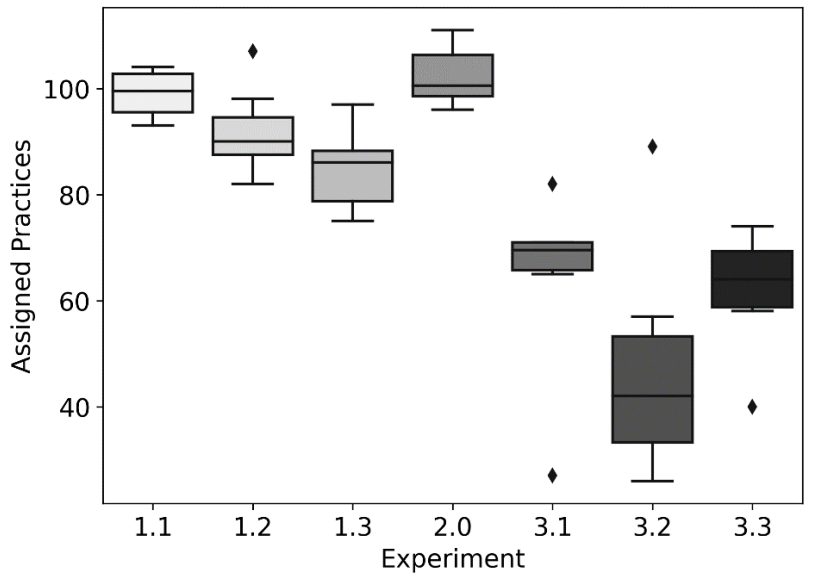

Fig. 5. Balance of the workload

assigned. As mentioned before, for experiments 1.1, 1.2, and 1.3, there were 6, 7, and 8 assistants available, respectively. Fig. 5 shows that the average number of assigned practices to each assistant decreases as the number of available assistants increases. This can also be seen in Figs. 2 and 4.

Another factor that affects the number of allocations is the balance of the workload. Fig. 5 indicates that experiments 3.1, 3.2 and 3.3, where no balance restrictions were applied, had either very atypical data of assigned practices, high variance, or both. On the other hand, the use of restrictions for balancing the workload led to no atypical data and low variances in the assignment of practices, as seen in experiments 1.1, 1.3 and 2. The atypical data of experiment 1.2 is small enough to meet the balance restrictions applied to the model.

In experiment 2, all the assistants were allowed to do all the practices. This experiment demonstrates that even if every assistant can do all the practices, the minimum number of assistants needed to comply with the schedule is six. Below this number of assistants, the model did not generate a feasible solution. Moreover, this experiment has the highest number of allocations, as demonstrated in Figs. 3 and 5 because only the minimum number of lab assistants was avail-

able. However, each assistant was assigned to a number of practices that ensured the balance of the workload.

Consequently, the assignment of practices becomes more flexible if the lab assistants have higher levels of skill and different skills because that allows for satisfying the personal requirements during the practices while considering the right balance between using as little labour as possible and keeping a high level of service. At the same time, a better workload balance for the assigned assistants is obtained.

4.2. Accumulation of skill

The accumulation of skill depends on the amount and type of practices performed by each lab assistant. The focus of experiments 1 and 2 was to guarantee a balanced assignation of practices and, thus, a balanced accumulation of skills. Figs. 6a, 6b, 6c and 6d show an equal increment of the assistants' skill throughout the practices, which then converge to a close value at the final practice. When comparing the accumulation of skills in experiment 1, it is evi-

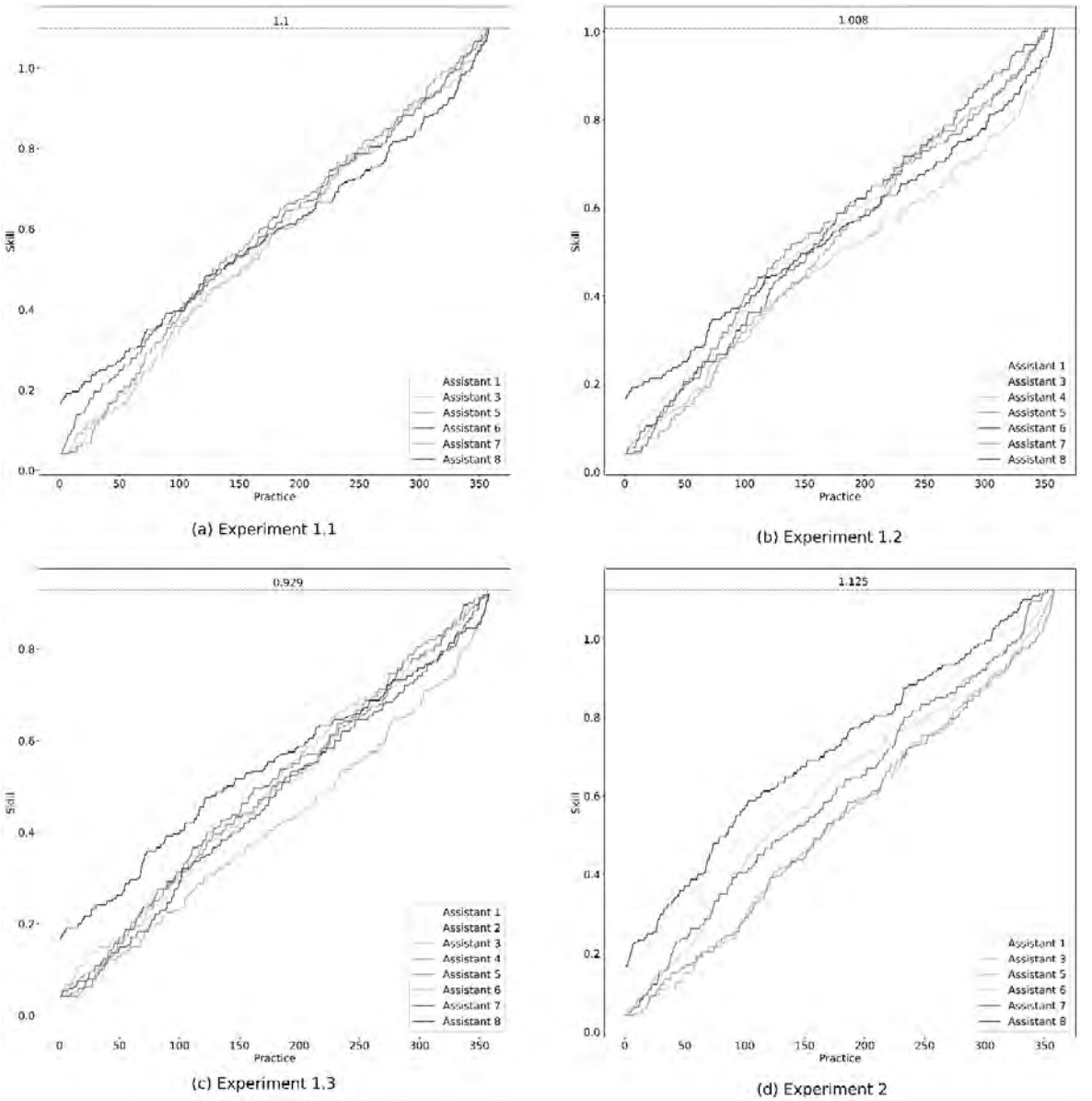

Fig. 6. Accumulation of skill during the practices

dent that the final skill level of the assistants is lower when more assistants are available to be assigned to the practices. This can be explained because the model distributes the total cumulative skill among a higher number of assistants, as demonstrated in Figs. 6a, 6b and 6c.

When comparing experiments 1.1 and 2, as they both assign the minimum number of assistants required to comply with all the practices, it was observed that the final accumulated skill in experiment 2 was higher than in experiment 1.1. This is because, in experiment 2, a higher number of allocations were made, derived from the fact that the lab assistants in this experiment were available for all the practices, which allowed for more training processes. In this pair of experiments, flexibility was contrasted as a benefit for the personnel and flexibility as a benefit for the company. When assistants are given more possibilities to define personal commitments in their working time and a schedule is planned in a way that considers such commitments, the assistants perceive greater flexibility; however, the company has less opportunity to train them and improve their skills, losing flexibility in the sense of not being able to later assign them to a greater number of practices.

4.3. Lab assistants training

Training is an important process for companies to carry out tasks and activities correctly. In the presented case study, the level of training for some skills is calculated according to an initial skill and the number of practices developed associated with that skill. For other skills, it is not possible to develop them using training (i.e., a bachelor's degree). In the first type of skill, the more lab practices are assigned, the higher level of knowledge is developed.

Training can be expensive (when assigning more than one person to a task), but the cost depends on the level of required expertise. In experiments 1.1, 1.2 and 1.3, the model was aimed at achieving outstanding levels of knowledge for all the assistants. Hence, for these scenarios, a total of 66%, 80%, and 89% of practices were used for training (more than one person per practice), respectively. This result shows that more assistants will cause more allocations and training to improve the minimum skill level.

In experiment 3, the model is aimed at minimising the number of practices and allocations while meeting a considerably basic level of knowledge. The number of practices allocated to two assistants is considerably low, 7%, 4%, and 3%, respectively. This means that the model is sensitive to the required knowledge level.

Fig. 7 presents the number of practices required to achieve a minimum skill level in the final practice for different numbers of lab assistants. In other words, for a fixed number of practices, different skill levels are achieved depending on the number of lab assistants. The more lab assistants are available, the lower the skill level achieved for a defined number of practices. Furthermore, to achieve higher skill levels,

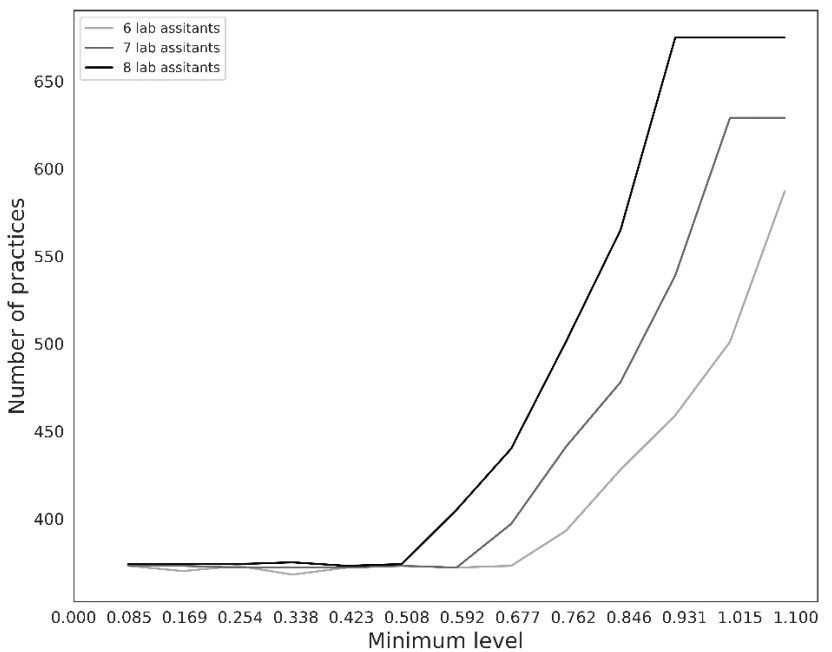

Fig. 7. Minimum level of skill vs number of practices

more practice allocations (training) are required. Hence, achieving high levels of skills is expensive.

Fig. 7 demonstrates that the number of practices required is relatively low for levels below 50 %; however, for levels between 50 % and about 90 %, intensive training is required since the number of required practices grows exponentially. Furthermore, when the number of lab assistants is eight, the maximum skill level that can be achieved is 90 %; for higher levels, the model becomes infeasible.

Conclusions

The labour scheduling problem is complex; however, when advanced decision-making methodologies are used, it is possible to optimise different objectives, including improving skills and meeting welfare constraints. Good scheduling allows for considering availabilities and exploiting them to generate welfare conditions. This can be seen as flexibility for workers to define available time slots.

Flexibility is an essential condition to be considered in labour scheduling models. It should be implemented in both ways, allowing employees to gain more skills and conduct more tasks and allowing organisations to offer flexible shifts to their employees. A good labour schedule should consider both aspects while keeping the number of required staff.

Multiskilled and well-trained workers can reduce the impact of adverse events, such as sickness or strikes. Employees who can perform multiple tasks are a valuable resource for organisations since they can reduce the impact of absenteeism. Therefore, organisations should include training in their labour scheduling.

A practice can be exploited for training unskilled staff and accumulating and reinforcing skills for skilled staff. Developing a practice with a partner helps to train unskilled people and acquire expertise for skilled people. Expertise is an important feature since lab practices are made for different users each term, and their requirements can depend on various dynamic aspects, such as disposition, previous knowledge, and cultural aspects. Hence, permanent training is vital for these kinds of tasks.

The schedule of practices should be made carefully. Bad planning can cause additional staff to attend practices. The day and time of practices depend on the class; however, this should be made carefully since overlapping lab practices that require similar knowledge could require more people to support them.

Further research on this topic can consider more objectives, such as environmental issues. While welfare aspects have been considered, sustainability is an important topic. This model could be extended to consider sustainability aspects, such as reducing the number of trips to the workplace.

Labour scheduling is very sensitive to situations that affect the population, such as pandemics. Hence, more studies could be conducted to analyse and develop strategies to mitigate these situations.

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Volume 15 • Issue 3 • 2023

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 1 April 2023
accepted: 10 July 2023

pages: 42-52

Reporting sustainable development in Polish commercial banks

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ABSTRACT
The article aims to present sustainable development reporting based on data obtained from Polish commercial banks, considering different approaches and scopes of presenting non-financial data, even though specific guidelines have been issued. The research procedure included a literature review of Polish and foreign literature and research using the case study method. The article presents examples of environmental, social and governance (ESG) activities reported by selected commercial banks in Poland in a case study. ESG activities are reported separately and presented as part of annual reports. Many of the banks' activities presented in the survey can serve as a model for others, as not all banks have a clearly written ESG strategy. A positive effect of reporting ESG activities is the clarification of indicators, such as reducing greenhouse gas emissions, eliminating exposure to the extractive sector or increasing "green" financing. This article can contribute to showing role models for banks in three areas, i.e., environmental, social and corporate governance. As a result, the authors tried to propose solutions where sector organisations could compare themselves in non-financial areas.

KEY WORDS
non-financial reporting, ESG, ESG reporting in banks

10.2478/emj-2023-0019

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Introduction

Environmental, social and governance (ESG) reporting in Polish commercial banks is a persistent phenomenon. It is increasingly more frequent for bank management to show activities in the field of ESG or CSR, demonstrating their commitment to this area. A new trend has emerged where bankers are expected to provide additional information on ESG data. ESG refers to how corporations and investors integrate environmental, social and governance issues into their business, meaning that it explicitly covers organisational governance matters (Gilan, Koch

Matuszak-Flejszman, A., Łukaszewski, S., & Budna, K. (2023). Reporting sustainable development in polish commercial banks. *Engineering Management in Production and Services, 15*(3), 42-52. doi: 10.2478/emj-2023-0019

& Starks, 2021). Reporting this data is an essential element of investor decisions. Legal regulations and guidelines appear in this area, and the pressure from investors and society contributes to the growing importance of sustainable development. The literature provides an increasing number of studies on various aspects of ESG reporting. For example, Ellili (2020), Sharma et al. (2020) and Suttipun (2021) examined the scope of reporting information on environmental, social and governance data and confirmed that although it is still at a low level, the size of information has increased in subsequent years. In addition, corporate governance information is the most significant part of ESG reporting, followed by social and environmental information. In addition, several recent studies (Manita et al., 2018; Arayssi et al., 2020; Shakil, 2021; De Masi et al., 2021; Yip, 2019) have verified the impact of various corporate governance mechanisms on ESG reporting. This only confirms that ESG reporting is increasingly recognised in the banking sector. All the more so, to identify business risks and increase investor and consumer confidence, disclosure of non-financial information is critical to managing the shift towards a sustainable global economy by combining social justice and environmental protection. In this context, disclosure of non-financial information helps measure, monitor and manage business performance and, therefore, sustainability accounting (Vukić, Vukowić & Calace, 2017).

Unfortunately, those responsible for ESG reporting rely on various methods, approaches and tools still being developed by national and international institutions that affect the statutory requirements and the content of voluntary reports (Kocmanova, Nemecek & Docekalova, 2012). Thus, reports published by various organisations are often criticised because they do not fully illustrate managing financial and non-financial elements to create company value (Hoang, 2018). In addition, given the diversity in ESG reporting, the comparability of ESG strategic results is problematic (Lokuwaduge & Heenetigala, 2016), and research by Singhania and Saini (2022) shows significant differences in the degree of implementation of ESG frameworks in different countries. Unfortunately, there is still a lack of consistency regarding features, attributes and standards defining individual ESG components (Billio, Costola, Hristova, Latino & Pellizon, 2021).

Bank management increasingly includes environmental, social and governance issues in their policies. This trend is strengthened by increasing pressure from the environment, investor expectations and growing social awareness. Significantly, bank managers see additional business opportunities and increased demand for sustainable products and services in ESG-compliant activities. This is the reason for the increase in the importance of ESG in the activities of banks and the support of their clients and society in these activities.

Therefore, a research question arises whether the information contained in ESG reporting can be compared in individual organisations of a given sector. When analysing the literature on the subject, an analysis of the unfunded reporting results must be made in the field of ESG in individual industries, particularly the banking industry. The identified research gap mainly arises because, contrary to disseminating financial information, the banking sector enjoys excellent freedom and discretion in reporting non-financial information on sustainability through ESG indicators, even though there are some guidelines.

ESG reporting is an essential and integral element of the annual reports in which these activities are presented. In addition, increasingly more specific announcements of further activities can be considered an ESG strategy for the coming years.

The article aims to present the information in the reports of selected banks in three areas (environmental, social and related to corporate governance) and to indicate similar and fundamental differences that various banks disclose. As a result, the authors tried to propose solutions under which organisations in a given sector could compare themselves in non-financial areas.

1. Literature review

1.1. Development of non-financial reporting

Non-financial reporting has been known in Polish banking for many years. Even before the reporting guidelines, the management of many banks in Poland reported social activities. These reports were mainly in the CSR field, sometimes with topics extended to activities in the field of corporate governance, which were assessed and distinguished by independent experts. The forms of this reporting varied; they were often described as social activities on the bank's website and only sometimes became an integral part of annual reports.

Initial ESG definitions can be found in 2004 when the United Nations first introduced the term. In addition, the Who Cares Wins report listed ESG elements by requiring research to address environmental, social and governance issues better and to further the necessary know-how investments, models and tools creatively and thoughtfully. The report noted that emerging markets should be given special attention due to the importance of sustainable development. Environmental, social and governance criteria should be considered and adapted to the specific situation in these markets. In the longer term, investment markets have a clear interest in contributing to better management of environmental and social impacts. Better integration of environmental, social and governance (ESG) factors into investments will ultimately contribute to more stable and predictable markets, which is in the interest of all market participants (Who Cares Wins, 2004).

The requirements for non-financial reporting have already been defined in the EU Directive (Directive 2014/95/EU), which also applies to banks and insurers; the areas listed in the directive concern environmental, social, employment, human rights and anti-corruption issues. In addition, this directive was supplemented by Guidelines on reporting non-financial information (Communication 2017/C 215/01) and Guidelines on reporting non-financial information: Supplement on reporting climate-related information (Communication 2019/C 209/01).

Other reporting guidelines are the Regulation on disclosure of information related to sustainable development in the financial services sector (Regulation 2019/2088) and the Regulation on the establishment of a framework to facilitate sustainable investments, amending Regulation (EU) 2019/2088 (Regulation 2020/852). Further reporting guidelines are included in the resolution on the Best Practices of WSE Listed Companies 2021 (Resolution No. 13/1834/2021). However, there is still a problem with the diversity in ESG reporting and the need for comparability of strategic results in ESG areas.

The essential elements of the sustainability reporting system include (Directive, 2022, p. 2464):

a) Environmental factors:
   - climate change — mitigation and adaptation,
   - water and marine resources,
   - resource use and circular economy,
   - pollution,
   - biodiversity and ecosystems;
b) Social factors:
   - equal treatment and equal opportunities for all (equal pay, development opportunities, integration of excluded people, prevention of violence),
   - working and employment conditions (working time, freedom of association, employees' right to information and consultation, occupational health and safety),
   - respect for human rights (fundamental freedoms, democratic principles and norms laid down in the International Charter of Human Rights and other fundamental UN conventions);
c) Management factors:
   - the role, composition and expertise of the entity's administrative, management and supervisory bodies regarding sustainability issues,
   - internal control and risk management systems used by the entity,
   - business ethics and corporate culture (anti-bribery and corruption, animal welfare),
   - activities and obligations of the entity related to exerting a political influence (including lobbying),
   - management and quality of relationships with customers, suppliers and communities affected by the entity's activities (including payment practices).

1.2. ESG reporting requirements and guidelines

Not all ESG issues are equally relevant to all organisations. Determining what information should be included in the report can be difficult, especially for managers of organisations who have yet to report information on elements of sustainability. A two-step ESG metric selection process in reporting proposals can help standardise an organisation's reporting practices and increase the supply and quality of data disclosed. Accordingly, indicators are divided into primary and sectoral. A more minor but carefully selected set of indicators is intended to help organisations' managers focus on reporting on key ESG areas in line with current and upcoming regulations and risks and opportunities relevant to their activity sector (ESG Reporting Guidelines, 2021).

The selection of indicators is also challenging in banks. Although the guide indicates a two-stage selec-

tion, practice shows that banks often list indicators that are considered as likely to be significant or even rarely significant. There are many reasons for this, but always showing ratios irrelevant to banking activity means that the report has more items and is more extensive, which does not translate into its quality.

The first step in choosing indicators should be to familiarise with the list of core indicators that every management of every organisation should consider, regardless of the sector of their activity. They refer to the areas listed in the NFRD, i.e., the environment, social and employee issues, human rights and anti-corruption (Directive 2014/95/EU).

The Non-Financial Reporting Directive (NFRD) imposes additional disclosure requirements on listed companies with over 500 employees. This directive aims to improve the quality of data available to banks and investors to direct funds towards sustainable investments (Bruno & Lagasio, 2021).

Taking care of their image and reputation, as well as the best-understood interest of the company and its shareholders, managers of listed companies should strive to apply corporate governance principles contained in the Best Practices while maintaining the proportionality and adequacy principles about individual needs, measured primarily by the size and type of enterprise and the scale of operations (Best Practices of Companies Listed on the Warsaw Stock Exchange, 2021).

Employee relations are an essential element in non-financial reporting. The relationship dimension concerns how the organisation treats its employees. It usually measures an organisation's commitment and effectiveness in generating employee trust and loyalty by applying the most responsible practices. This is usually related to the quality of employment, occupational health and safety, training, development, diversity and equal opportunities (Esteban-Sanchez, de la Cuesta-Gonzalez & Paredes-Gazquez, 2017).

Increasingly, key ESG issues are discussed in annual activity reports. Typically, this type of information is limited to a few key topics and indicators to suit the style and format of the financial statements. Additional information is often disclosed through a website or sustainability report.

The most common method of reporting in organisations worldwide is a separate sustainability report. It allows for collecting all information on environmental, social and corporate governance issues in one document. The integrated report combines elements of the financial report and sustainable development issues in one document, showing how the organisation's strategy and value-building model affect the undertaken ESG activities and their results. For this reason, this format is more often chosen by the management of more progressive organisations with a well-developed ESG management system.

Integrated reporting is promoted by the International Integrated Reporting Council (IIRC). To facilitate comparability of reports published by organisations, disclosures of ESG information are encouraged by widely accepted reporting standards and frameworks, particularly GRI, IIRC, and SASB. The GRI and IIRC guidelines are most often used in the banking sector in Poland.

Materiality is one of the most important aspects to consider when preparing a sustainability report. Reporting excessive or irrelevant information may make it easier for recipients to understand the report's content or prevent vital information from being missed. The materiality perspective set out in the NFRD considers financial, environmental and social materiality. According to this approach, the organisation's management should disclose the actual and potential ESG risks and opportunities that may significantly impact its operations and financial results and how the organisation's activities may affect broadly understood sustainability issues.

Company disclosures on managing climate change risks and opportunities have so far been voluntary. One of the leading standards in this area is the formula proposed by the Task Force on Climate-Related Financial Disclosures (TCFD). This body was established in 2015 by the Financial Stability Board (FSB) to develop consistent and comparable disclosures on climate-related financial risks and increase the amount of available and reliable information for businesses, banks and investors. TCFD published its recommendations in 2017 and updated them in 2021. The TCFD recommends climate risk disclosures across four areas, defining eleven particular requirements for what should be reported (Climate Risks and Opportunities Disclosures, 2022).

Bank management chooses various reporting methods, e.g., activity and ESG report, sustainable development report or integrated report. Banks have been implementing and publishing information on various social and environmental activities for many years. Recently, these activities have taken the form of ESG reports. In the publication, selected elements of ESG activity reporting have been limited to several largest commercial banks in Poland.

Since 2019, the Warsaw Stock Exchange has introduced the WIG-ESG, which includes organisa-

tions recognised as socially responsible. The banks in the index include PKO Bank Polski, Bank Pekao S.A., ING Bank Śląski, mBank, Bank Millennium and Bank Handlowy (Warsaw Stock Exchange).

2. Research methods

The following research on ESG efforts reported by selected commercial banks in Poland is aimed at presenting the current status of existing sustainability efforts. Accordingly, a case study method was applied to selected commercial banks and a specific period. From the point of view of the research process, it is qualitative.

A case study is an empirical research in which a certain phenomenon is studied in a real-life context (Lima et al., 2023). The case study method is derived from grounded theory that aims to construct new theory concepts capable of explaining emerging phenomena. In the field of qualitative research, grounded theory is gaining prominence as an approach to developing theory from data (Monteiro et al., 2023). According to Rashid et al. (2019), a case study helps explore a phenomenon in a given subject area using various data sources. Case studies can be divided according to their content and ultimate purpose (exploratory, explanatory, descriptive, or by a certain number of cases) (Voss et al., 2002). A common trend in all types of case studies is to try and explain why a certain decision or several decisions were taken, how these decisions were implemented, and what is the effect of implementing these decisions (Lima et al., 2023).

In this study, the following steps were taken: the study topic was defined, and literature was reviewed on the development of non-financial reporting and the requirements and guidelines for environmental, social policy and corporate governance reporting. Then, key commercial banks were selected, data was collected, analysis was performed, and a summary was formulated in tabular form, which was divided according to environmental, social and corporate governance activities (Fig. 1).

This work mainly aimed to analyse sustainable development in selected Polish commercial banks. The development of these studies should enrich the knowledge of environmental, social and corporate governance activities taken in Polish commercial banks.

3. Research results: examples of ESG activities reported by selected commercial banks in Poland

3.1. ESG activities reported by ING Bank Śląski

ING Bank Śląski publishes reports on the capital group's activities, which contain all ESG elements. The beginning of the report emphasises the guiding principles and values and the aim to respond to modern world challenges. That is why it created an ESG strategy, which is part of its business strategy. As basic activities in the field of the environment, the bank indicates counteracting climate change and supporting customers in environmental transformation. Entrepreneurship and opportunities point to equal social opportunities and care for employee health. The bank presents activities by regulations and the best market practices in ethics and compliance with regulations. The annual summary has been divided into three elements: environment, community and corporate governance (Management Board Report on the activities of the ING Bank Śląski Capital Group in 2021, 2022). ING Bank Śląski also published the ESG Strategy for 2022–2024, which included its priorities divided into activities supporting clients and society and detailing the elements of the environment, entrepreneurship, equal opportunities, ethics and compliance with regulations (ING Bank Śląski, ESG Strategy for 2022–2024).

The summary of 2021 indicates several essential facts that confirm the implementation of the planned activities that are part of the ESG. In terms of the environment, it means a 28.4 % decrease in CO2 emissions and the production of 87 MWh of electricity by its photovoltaic panels. In the new Ecological Declaration, the bank stated that after 2025 it would not finance customers whose activities are directly

Fig. 1. Research process flow chart

dependent on steam coal to a degree higher than 5 %. Out of concern for the environment, the Bank also does not finance, among others, activities related to the cultivation and production of tobacco and with a negative impact on protected areas, forestry and animal welfare. By the end of 2023, the Bank has committed to allocate PLN 4.5 billion in the corporate area to finance renewable energy sources and pro-ecological projects, PLN 500 million to support local government units in pro-environmental investments (project: "Green commune/local government"), PLN 300 million for further support and promotion of electromobility. The bank engages in social activities through two of its foundations (the ING Children's Foundation and the Polish Art Foundation) and partnerships and support from other organisations. The total amount of donations made for these activities in 2021 is PLN 2.7 million, and 1045 hours were dedicated to employee volunteering. Regarding corporate governance, the Bank emphasises that its organisational culture is based on clearly defined ethical principles and pays great attention to diversity and gender equality. The share of women on the Management Board is 50 %, and the ratio of the total remuneration of women to men is 99 % (Report of the Management Board on the activities of the ING Bank Śląski Capital Group, 2021).

3.2. ESG activities reported by Santander Bank Polska

Santander Bank Polska reports on ESG activities by publishing a separate report. Its integral part is the climate report, developed using the TCFD recommendations. In 2022, the bank verified the ESG materiality matrix by making a preliminary materiality assessment. The process was carried out according to the pilot methodology developed by the Santander Group.

The Bank points to a remuneration policy that meets legal requirements regarding corporate governance. It emphasises that the bank's remuneration practices consider diversity and enable the acquisition and retention of the best-qualified employees through a comprehensive benefits package. From 2021, one of the criteria for determining the number of bonuses awarded to Members of the Management Board and the Chairman of the Supervisory Board is the assessment of the achievement of the goals of the Responsible Banking strategy, including tasks that are environmentally friendly and counteract climate change. From 2021, one of the bank's operational strategy goals is to achieve 10 % of the "CO" grade. In the report, the bank publishes specific results regarding the adopted goals, namely, the position in the Top 10 employers (Top Employer Certificate), women in managerial positions (34.7 %), pay equalisation measured by EPG (2.4 %), the number of people financially strengthened (130 992 since 1 January 2019), green financing (EUR 214 million), electricity from renewable sources (82 %), elimination of single-use plastics (100 %), scholarships, internships and apprenticeships (6 422 people), number of beneficiaries of activities (305 000) (ESG 2021 Report, Santander Bank Polska).

In its strategy, Santander Bank Polska emphasises supporting the implementation of the global Net Zero strategy's goals through a two-pronged approach: making efforts to reduce greenhouse gas emissions from internal emissions (e.g., electricity consumption, business trips or fleet operation) and by the TCFD recommendations focusing on issues resulting from the bank financing.

The bank's management has committed to cease financing energy companies with more than 10 % of coal-fired energy production by 2030 and to reduce its exposure to thermal coal producers. From 2050, the bank plans to achieve climate neutrality.

The direction of the business strategy for 2021–2023 is to care for the employee. The bank notices, among other things, the value that results from diversity and shows activities supporting diversity in the bank. With the adopted policies in this regard, the bank has set specific goals to be achieved by 2025, i.e., the share of women on the management board is to be at least 30 % (in 2021, it was 11 %). Women's share in the Supervisory Board forms is 40-60 % (in 2021, it was 40 %). The bank demonstrates that it conducts activities supporting employees with disabilities. The goal is also to close the wage gap by 2025.

For 12 years, the bank has been running a barrier-free service programme to provide access to services and products to customers with individual needs (people with disabilities and seniors). The bank shows that its products are adapted to the ESG rules. The bank also offered financial solutions in which the margin amount is based on the customer's social and environmental criteria fulfilment.

In the report, the bank presents the impact of its operations on the environment, specifying, for example, the decrease in total electricity consumption (by 8.8 %) and the percentage share of purchased RES electricity (81 %). It shows the trend of eliminating fleet cars with diesel engines and the increase in

hybrid/electric cars. Showing such trends forces the continuation and publication of results in future reports (Strategy of Santander Bank Polska, 2022).

3.3. ESG activities reported by PKO Bank Polski

PKO Bank Polski adopted a strategy for 2023/2025 in which it defined ESG tasks. In the field of the environment, it wants to become a leader in financing transformation in Poland. The bank has reduced its CO2 emissions by over 60 % (2019–2021), the consumption of A4 paper by 65 % in the last five years, and its involvement in high-emission industries, which amounts to 0.5 %. It plans to continue its ecological initiatives and become the first choice bank for companies that invest in their transformation. The report refers to GRI (Global Reporting Initiative) indicators.

The bank adopted indicators in the area of ESG and included them in the non-financial objectives of the Capital Group for the coming years. It committed to eliminating exposure to the coal mining sector by 2030 and increasing the volume of green financing by at least 5 % annually. Involvement in green funding of the bank's assets will be maintained at least three times higher than financing high-emission sectors. In 2021, the bank increased green financing by 83 %, thanks to which the value of involvement in funding green was 3.5 times higher than in high-carbon financing. In 2021, the bank comprehensively estimated energy and fuel consumption and calculated the carbon footprint. In 2021, the bank conducted an energy audit and defined tasks, the implementation of which should reduce energy consumption. These tasks focus mainly on optimising the use and modernisation of automation controlling heat sources and technical installations in real estate (ESG in the PKO Bank Polski Group, 2021).

One of the bank's strategic goals is to simplify and streamline processes by reducing paper documentation (SMARTOP project). The Capital Group has adopted and implemented a policy for Financing the High-Carbon Energy Sector in line with the European climate policy and the pursuit of zero emissions in 2050. The policy aims to change the loan portfolio structure by gradually reducing the exposure to customers and transactions based on coal as an energy carrier while increasing the exposure to supporting zero-emission or low-emission energy sources. The bank assesses the impact of environmental, social and management-related factors on the creditworthiness of corporate clients and the segment of organisations and enterprises. Identifying ESG risks makes it possible to identify projects that do not meet increasingly stringent environmental and social requirements. The assessment of ESG risks has become an element of assessing the borrower's business model for new and existing customers. It has an impact on the terms of the credit decision. The strategy states that, together with other entities of the group, the bank supports economic development by financing investments in new technologies, modernisation of technological lines and energy-saving projects (Strategy of PKO Bank Polski for 2023–2025, 2022).

In the published financial results of the bank for 2021, the bank also details the ESG goals regarding reducing greenhouse gas emissions, eliminating exposure to the mining sector, and increasing "green" financing. Thus, it shows an additional reinforcement of this message. The goals presented here also apply to the share of women in critical managerial positions (the target is above 35%, where the value for 2021 is 38 %), employee turnover rate (value below 14 %, where the performance for 2021 is 13.1 %) and voluntary leave (the target is below 7 %, and the value for 2021 is 8.1 %) (Presentation of results for 2021, PKO Bank Polski).

3.4. ESG activities reported by Bank Pekao

In 2021, Bank Pekao adopted the ESG strategy, which defined the directions of change for 2021–2024. In the field of ESG, it wants to be a responsible bank, providing long-term value to all stakeholders and future generations, more involved in Poland's energy and ecological transformation and environmental protection by the principles of the European Green Deal. This strategy is based on three standard ESG pillars and is integral to the bank's business strategy. It assumes that in 2021–2024, it will organise financing for new sustainable projects for at least PLN 30 billion. The share of green financing assumes an increase to over 4 % of the portfolio by financing, i.e., wind farms, photovoltaic installations, low-emission transport and ecological construction. The report indicates that it will strengthen activities to support the sustainable development of society and the economy. The bank, among other things, plans to increase the involvement of employees in activities for the benefit of society and the environment (increase in employee volunteering from 4.4 thousand to 5.5 thousand

Tab. 1. Selected ESG activities of the surveyed banks

	ING Bank Śląski	Santander Bank Polska	PKO Bank Polski	Bank Pekao
Environment (E)				
E-P1 Greenhouse gas emissions	decrease in emissions by 28.4 %	by 2050, the group is to be zero-emission	reduction of emissions by 61.8 % y/y	in 2021, it started calculating greenhouse gas emissions
E-P2 Energy consumption	measures to reduce energy consumption; reduction of electricity consumption by 50 % by 2030	modernisation of lighting, a decrease in electricity consumption by 8.8 % y/y, a fourfold reduction in diesel fuel consumption	conducting an energy audit and identifying tasks, the implementation of which should reduce energy consumption	policy on optimising energy consumption shows a decrease in consumption
E-P3 Climate-related risks and opportunities	lending to ecological projects, no coal financing after 2025	assessment of the impact of financed projects on the environment	study of the impact of credit transactions on ESG issues and their categorisation	achieving its own climate neutrality by 2030
E-S3 Water consumption	reporting the reduction in consumption	showing consumption; reducing consumption through technological solutions	for the purposes of the report, an attempt was made to estimate the group's water consumption	reducing consumption (sanitary faucets with aerators)
E-S5 Impact on biodiversity	construction of a flower meadow in Katowice	negligible impact on biodiversity	-	-
E-S6 Waste management	waste segregation, no mixed waste bins	-	shows waste generated by the bank other than municipal waste	transfers paper documentation for specialist disposal, IT carriers, furniture, household appliances/ electronics
Society (S)				
S-P1 Diversity in supervisory bodies	no group consists of more than 70 % of employees of the same sex, nationality, age	supporting diversity; participation of women on the management board, min. 30 % until 2025 and 40 % on the supervisory board	diversity by gender, age and experience	reported by type of employment, type of employment contract and region, and gender
S-P2 Equal pay index	maintaining the wage difference ratio of no more than 1 %	Equal Pay Gap of 2.4 %, the goal is to eliminate the pay gap by 2025	female to male pay ratio (until 2019 — 65)	the wage gap between women and men (37.9 %)
S-P3 Employment rotation	monitors the process of employee rotation and examines their satisfaction	gives the employment turnover rate (21 %)	provides new employees and rotation in the bank and the bank's capital group by age and gender	total number and hiring rates of new hires and staff turnover by age group, gender and region
S-S1 Occupational health and safety	health and safety training	health and safety training, reports accidents at work	OHS training, in 2021, 69 accidents were reported	health and safety training
S-P5 Human rights policy	customer evaluation also concerns respect for human rights	supports the human rights policy and applies it to suppliers, customers and communities	the bank's policy regarding respect for human rights is included in the bank's policies and regulations	building employee awareness and continuous improvement of human rights protection procedures
Corporate governance (G)				
G-P1 The structure of management bodies	presents the structure, competences and remuneration of the management board and the supervisory board	presentation of the management board by age structure	organisational structure, presentation of the remuneration of the management board and the supervisory board	organisational and management structure
G-P2 Ethical codex	banking code of ethics	banking code of ethics	preparation of the Supplier Code of Ethics	code of ethics
G-P3 Anti-corruption policy	anti-corruption activities	anti-corruption programme	counteracts all corrupt practices	specialised coordinating positions/teams responsible for anti-corruption activities
G-P4 Violation reporting mechanism	possibility of anonymous reporting	the "Respect and Dignity" policy describes the mode and forms of reporting	employees are free to report	whistleblowing policy
G-S1 Data protection policy	regulations regarding the protection of personal data	Information Security Management System	security standards in the bank's capital group	principles of personal data protection

Source: elaborated by the author based on available annual/ESG reports of the surveyed banks.

hours). The strategy also emphasises the goals of increasing employee satisfaction and commitment thanks to development programmes, succession plans and an attractive remuneration system related to the results. It also cares for equality and further reduction of the gender pay gap by 5 % and maintains a balanced level of women and men in managerial positions, i.e., 58 % of women in executive positions at the end of 2020 (ESG Strategy of Bank Pekao S.A. for 2021–2024, 2021).

In September 2020, the bank's management decided to create an ESG unit to become a centre of competence in environmental, social and corporate governance issues and deals with, i.e., setting directions, coordinating activities, monitoring and monitoring and non-financial reporting. In December 2020, the ESG Council was also established, whose task is to recommend to the bank's management board the necessary actions in this area. The bank published the completed ESG activities in 2020 and 2021. In March 2021, it organised the issue of fixed-coupon ten-year ESG bonds worth PLN 1 billion For PKN Orlen. The bank was a co-organiser, dealer and co-bookkeeper for the first issue of sustainable development bonds on the Polish market (sustainability-linked bonds) carried out by Tauron Polska Energia. In March 2021, the bank increased its involvement in RES by signing a loan agreement with PAK PCE Fotowoltaika Sp. z o. o. (in consortium with PKO BP and mBank) to finance the most prominent photovoltaic farm in Poland with a capacity of 70 MWp (Key ESG initiatives at Bank Pekao S.A. in 2020 and 2021).

The report on the activities of the Bank Pekao Capital Group for 2021 also presents elements of the ESG strategy. The report shows specific indicators of the ESG strategy broken down into targets adopted for 2024 and the implementation at the end of 2020 and 2021. In the report, the bank also details the consumption of energy, paper, waste management, and car fleet, which shows that the change processes are planned and systematically implemented. The strategy assumes that the amount allocated for social and environmental purposes will increase yearly, and a specific goal for 2024 has also been set here. Taking care of the highest standards of corporate governance, the key goals are to increase employee satisfaction and commitment. Another element is the care for equal rights, further reduction of the pay gap, and maintaining a balanced number of women and men in managerial positions (Report on the activities of the Bank Pekao S.A. Capital Group for 2021).

The presented ESG activities in individual banks indicate a broad approach to reporting in this area. Certain activities are reported even though they are insignificant to the operations of banks. Such action means that banks, observing a wide range of reports from others, want their report to be very detailed. Determining the information that should be included in the report takes work. A carefully selected set of indicators would be a better solution. This approach is suggested in the ESG Reporting Guidelines (ESG Reporting Guidelines, 2021).

The banks' choice of indicators is varied, which is not entirely a disadvantage of reporting, but undoubtedly the detail of reports does not translate into quality at all. In many cases, banks report, for example, water consumption, electricity consumption, waste management or even the impact on biodiversity, which is not crucial when looking at their activity profile. However, this has a temporary meaning as this allows showing that when verifying given ESG elements to assess clients or suppliers, these specific standards also apply to the assessing business.

It can be assumed that in several years, ESG elements unrelated to the actual operations of banks will be included in the reports, as it will no longer be possible to present spectacular effects of reducing their consumption. This will also happen due to greater awareness and experience in reporting and reading ESG reports.

Many bank managers show the planned values of individual indicators in ESG strategies. It is worth noting that we are most often dealing with a tendency to show specific ratios in the surveyed banks. If long-term goals are defined, they are usually precise and measurable. This proves a severe approach to planning individual ESG elements and a willingness to monitor and account for these declarations.

Conclusions

In recent years, Polish commercial banks have been putting efforts into developing appropriate reporting of ESG activities. This article presents reporting forms, legal frameworks and examples of environmental, social and corporate governance activities reported by selected commercial banks. ESG activities are reported separately and presented as part of annual reports. In their strategies, banks present planned ESG activities for the coming years. The fact that these activities are planned by indicating specific indicators and accounted for in a given year is

a very positive effect of the growing ESG awareness. Of course, it is possible to find some commercial banks with a vague ESG strategy and ESG activities without precise measures. However, these banks are intentionally not presented in this study. Many of the banks' activities presented in the study may serve as a model for others. ESG reports in Polish banks are often very extensive, which is not always a positive element. Such an unnecessary increase in the volume of reports often makes them illegible and focuses on unimportant aspects of a given bank's operation. A positive effect of reporting ESG activities is the specification of indicators, e.g., reducing greenhouse gas emissions, eliminating exposure to the mining sector and increasing "green" financing. An additional strengthening of ESG activities is the inclusion of the assessment of ESG risks in the assessment of the borrower's business model and the impact of this assessment on the conditions of the credit decision. This shows a particular trend in the market of deliberate influence of banks on their current and potential customers. In this way, the financial system can act as a catalyst for the transition to a more sustainable economy by all market participants. This will undoubtedly contribute to a broader and more specific reporting of ESG activities by the bank and other entities using their services.

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sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 15 April 2023
accepted: 15 July 2023

pages: 53-68

The importance of resources in achieving the goals of energy companies

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ABSTRACT
The fundamental transformation of the global energy sector challenges Polish energy companies to define new organisational goals. To a large extent, these objectives determine an energy company's competitive position and ability to develop in the long term. However, achieving the set goals requires adequate resources. This paper mainly aims to identify and assess the resources used to achieve organisational goals in Polish energy companies. Based on a literature review and data collected from 110 Polish energy companies, the authors identified and assessed resources for achieving their organisational goals. The study confirmed that the organisational goals pursued by energy companies are interrelated. Analysis of the results of the basic organisational goals postulated by Polish energy companies showed that economic goals, such as "market share growth", "implementation of innovative solutions", and "quality of products/services", are among the most important. The study showed that the resources held by energy companies are important for implementing separate organisational goals. Human resources received the highest rating and were considered of the greatest importance for the implementation of the goals of "sector development", "uninterrupted energy supply", and "sustainable development". The paper assesses and discusses the characteristics of Polish energy companies' organisational resources and organisational goals. The contribution of this study is the highlighted importance of resources in achieving the organisational goals of Polish energy companies. The main practical implication of this article is to stress the existence of links between the individual goals of companies in the energy sector and to highlight the importance of the different resource categories they possess for achieving specific objective bundles.

KEY WORDS
organisational resources, organisational goals, energy sector companies

10.2478/emj-2023-0020

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Introduction

The energy sector is undergoing critical reforms resulting from changes in international regulations, which are shaping a new framework for the functioning of the market (Angelopoulos, Kontakou & Pollalis, 2019). In 2014, the European Union formulated a clear strategy for the energy sector, assuming a safe and effective transformation meeting the requirements related to changes in the climate and energy (Efimova, Ruchkina & Tereshina, 2018). Polish legislation has responded to European Union regulations in the field of energy and climate policy. However, the

Chwiłkowska-Kubala, A., Malewska, K., & Mierzejewska, K. (2023). The importance of resources in achieving the goals of energy companies. *Engineering Management in Production and Services, 15*(3), 53-68. doi: 10.2478/emj-2023-0020

transformation process is demanding due to the specificity and condition of the Polish energy sector (Kaczmarek, 2022).

Poland's energy supply continues to be dominated by fossil fuels (85 % of total energy supply in 2020), of which coal (40 %) has the largest share, followed by crude oil (28 %) and natural gas (17 %). Coal continues to play a key role in the energy system and the Polish economy. Among the 31 member states of the International Energy Agency (IEA), in 2020, Poland had the highest share of coal in energy production, total energy supply, total marginal consumption and electricity production and the second largest share in heat production. The trajectory of the energy sector in 2021 (growing demand, higher fossil fuel consumption and rising emissions) is not in line with the objectives needed to support the transformation of the energy system and combat climate change (International Energy Agency, 2022).

Despite the continued dominance of coal, Poland has achieved significant success in energy transformation in terms of renewable energy sources (RES) and has become one of the fastest-growing photovoltaic markets in the EU (Instytut Energetyki Odnawialnej, 2021). According to the Energy Market Agency's (Agencja Rynku Energii, 2023) data, multi-billion investments in RES and distribution are planned in the coming years. Moreover, in October 2022, the Polish government announced an investment programme for Polish nuclear energy (Popczyk, 2022).

Energy sector researchers highlight the need to transform energy production models resulting from European Union regulations (Vasilakos, 2019). Therefore, research is being conducted on the goals of different stakeholder groups (Matos and Silvestre, 2013) and value capture (Bryant et al., 2018). In Poland, energy companies face the challenge of adapting to new positions (Nogalski et al., 2016b). Considering the postulates and legal regulations of the European Union (European Commission, 2008; Komisja Europejska, 2014), the global political situation affecting the supply of energy around the world (Korosteleva, 2022), and observing current trends in the transformation of energy companies' business models in the context of dynamic changes in the environment (Giones et al., 2019), energy sector companies in Poland face the challenge of shaping new business models, and thus looking at their organisational goals anew. As a result of a literature review on the subject, the authors identified a research gap in the realisation of the organisational goals of energy companies. The considerations account for the perspective of organisational resources, which are an important factor in achieving various goals within an organisation. Resources affect the level of an enterprise's competitiveness, and when used effectively, they contribute to its development. Company goals should, therefore, consider the level and quality of resources and determine ways to improve them by acquiring new resources and developing existing ones. In addition, they should also consider the resource gap and propose ways to reduce it (Kunasz, 2006).

The general condition of the technical infrastructure of the Polish energy sector is unsatisfactory. Transmission grids, transformer stations and electrical power plants require modernisation, while the density of transmission lines is insufficient to implement innovative solutions (Zakrzewska et al., 2020). The modernisation of the energy sector, in which the postulates of energy and climate policy will be implemented, is associated with the need to implement advanced digital solutions and the use of ICTs (Hilty et al., 2009; Lange et al., 2020). Most technologies also require employees to acquire new competencies and the energy sector staff to be retrained (Smokvina et al., 2019). The dynamically growing interest in green energy among energy consumers is forcing a change in the attitudes and behaviours of energy producers towards being more pro-ecological (Liakhovych et al., 2021). Innovations in the energy sector require huge financial outlays. The Polish Energy Policy 2040 highlights significant investments in the modernisation of the energy system across the country and in fixed assets in energy companies in the coming years, which involves high expenditure on capital goods (Lisowski et al., 2021).

Given the above, it would appear highly appropriate to research the relationships between the organisational goals of energy companies and the resources held by these companies. The article aims, therefore, to identify and assess the resources used by Polish energy companies to achieve their organisational goals. This article is part of a wider research project on the business models followed by energy sector companies in Poland. With reference to the main objective of the paper, the following research questions were formulated:

- What are the organisational goals of energy companies in Poland?
- Which categories of organisational goals are interrelated in Polish energy sector companies?
- What is the resource base of energy sector companies in Poland?

- How important are organisational resources from the perspective of the main goals of energy companies in Poland?

The paper is structured as follows. Section 2 presents the theoretical background, discussing organisational goals, categories of resources in Polish energy sector companies, and the importance of the resource base from the perspective of energy companies' goals. Section 3 includes the methods and the research sample. The research results are then introduced and discussed in section 4, and the final part of the paper provides conclusions, limitations and further research directions.

1. Literature review

1.1. Organisational goals of energy sector companies

Organisational goals are a key issue in management science; however, the question of formulating goals and their consequences has many ambiguities (Linder & Foss, 2018). Organisational goals refer to determining the direction of an organisation's activities (Simon, 1964). Kotlar et al. (2018) noted that organisational goals are the result of negotiations between different stakeholder groups. Consequently, the set goals relate to various dimensions, such as production, inventory, sales, market share and profitability. Lee, Costello and Lee (2021), referring to the balanced scorecard, considered an organisation's goals in terms of internal business goals, financial goals, the customer perspective, and learning and growth. They also pointed to the category of goals related to the IT perspective.

Hall and Lobina (2004) suggested that organisational goals do not always coincide with public goals. While discussing the companies' operation in the energy sector in recent years, the issue of sustainability goals received much attention (Latapí Agudelo et al., 2020). This paper, however, attempts to determine the importance of various goals of energy companies in Poland. Although the list of goals set and pursued by energy companies remains open, the article presents goal categories as they emerge from literature analysis on the subject, which also identifies the main areas addressed by energy companies' goals.

The first area is contributing to the development of the energy sector in Poland. The business models of contemporary energy companies are undergoing significant changes due to, among other things, a significant increase in the level of varied sources of renewable energy (Bryant et al., 2018). The need to transform energy companies' business models also arises from the changing technological environment (Chasin et al., 2020) and the consequent need to adjust the activities carried out as a part of operations to Industry 4.0 concept assumptions (Schaeffer, 2015). The business models of energy companies in Poland are characterised by a traditional configuration (Brzóska, 2016), and it is these traditional characteristics that need to evolve to fit the changing environment (Nogalski et al., 2016a).

The second area is profit maximisation and market share growth. Such general organisational goals as strengthening market position and improving performance are also characteristic of energy companies (Westerman et al., 2020). Maintaining an adequate market share emerges as the next necessary course of action for energy companies. For example, in the past, the success of German power plants was based on centralised ownership and mass production. Today, growing environmental awareness, the increasing liberalisation of the energy market, and the decentralisation of production require companies to take appropriate measures to maintain or strengthen their market position (Dellermann et al., 2017).

The third area is investing in renewable energy sources and sustainable development. The energy sector needs to increase its commitment to diversifying energy sources, including renewable energy (Bryant et al., 2018). Zolfaghari Ejlal Manesh and Rialp-Criado (2017) analysed the business models of nine companies involved in renewable energy; however, they pointed out that the Spanish electricity market is dominated by large "incumbent" companies with a better financial situation and technological background. As a result, small start-ups focused on renewable energy innovations are seen as a market threat and are being taken over by large market players. The concept of sustainability requires the attention of energy companies because it raises social, economic and environmental issues that should be considered in the sustainable business models of today's energy companies (Matos & Silvestre, 2013). Kolk and van den Buse (2012) suggested that energy companies should engage in efforts to provide sustainable energy. Changes in energy production models result from European Union regulations (Vasilakos, 2019) or global energy policies oriented towards ensuring a sustainable energy path, as set by the UN Sustainable Development Goals (Kim, 2019).

The fourth area is the customer perspective (providing the highest possible level of quality of products/services offered; providing customers with products/services at the lowest possible price; ensuring uninterrupted energy supply to customers). The customer perspective is one of the key elements of the business model. Energy companies' service and customer orientation are among the key factors in their success (Meyer et al., 2021). Chasin et al. (2020) pointed out that energy companies' relationship with their customers tends to be limited to issuing-receiving bills and meter readings. Responsible pricing by energy suppliers is an important element of viable social responsibility measures (Weder et al., 2019). The importance of energy for economic development and society as a whole is indisputable (Kolk and van den Buuse, 2012). Thus, the role of energy companies in ensuring uninterrupted energy supply is important.

The fifth area is the implementation of innovative solutions. Although the energy sector appears to be one of the most closely regulated and thus resistant to change, including digital transformation (Bradley et al., 2015), the literature raises issues of innovation in energy sector companies. Munsamy et al. (2019) highlighted the variety of technology tools used in energy management, including business process automation. Nogalski, Szpitter and Jablonski (2016) raised the importance of innovative solutions/new technologies from the perspective of business models. Exploring the importance of virtual power plants (related to the Internet of Things), Dellerman, Fliaster and Kolloch (Dellermann et al., 2017) stressed the importance of managers being able to identify elements of the business ecosystem.

1.2. Organisational resources in the Polish energy sector

This section of the article analyses the categories of resources included in the empirical research carried out among companies in the energy sector.

The resource-based view has remained one of the most popular perspectives for conducting empirical research related to organisations (Nason & Wiklund, 2018; Zhao & Pan, 2021). As Wernelfeld (1984) emphasised, a company's resources are all the physical assets, intangible assets and organisational capabilities that the company owns and controls. According to the resource-based view, above-average corporate performance, achieving a certain competitive position and sustainable competitive advantages are explained by focusing on the company's internal resources and prioritising them over external factors. The theory assumes that the organisation is a bundle of resources and skills (Amit & Schoemaker, 1993). Companies within a sector may differ in the resources they possess. Barney (1991) postulates that resources are valuable if they have strategic value, are rare, have no substitutes and are difficult to imitate. Such qualities are characterised by intangible resources, which are diverse in nature, unique, immobile and relatively resistant to imitation (Othman et al., 2015).

The resource-based-view of the company assumes the division of resources into various categories, among which the most frequently mentioned and those recurring in the proposed classifications are (Amit & Schoemaker, 1993; Barney, 1991; Grant, 1991; Wernerfelt, 1984): human, physical, financial and technological. Therefore, these resource categories will be analysed in the context of energy sector enterprises.

Regarding human resources in the energy sector, it can be noted that according to empirical studies, employment in the energy sector is gradually increasing all over the world, including in Poland (Czako, 2020). The reported increase in employment is primarily related to the so-called green transformation and the development of such fields of energy as solar, wind and hydroelectric power, and the increase in the use of biogas or biomass. This makes it necessary to transform the energy system into a post-carbon system and, consequently, introduce technological and technical changes. The financial support offered by the European Union in this area is also important (Martinez-Rodriguez & Vera-Martinez, 2020). All these factors contribute to modernising the existing energy system and offering new products and services. Progressive change requires, on the one hand, an increase in employment (the creation of new jobs and positions) and, on the other, the formation of entirely new skills and competences. These include multidimensional, interdisciplinary and specialised competences, but also social competences. Employees with both technical, investment and team management competences are required. There is also the problem of retraining, education and vocational training of current human resources in the energy sector, as well as the recruitment of new employees (Černý et al., 2021; Ram et al., 2022). Graduates from secondary technical schools and professionals with higher education, including engineers, are needed.

For this reason, the Sectoral Qualification Framework for the Energy Sector was developed to ensure that the education system is better aligned with the actual market needs. Based on the above considerations, it can be concluded that human capital is one of the key resources determining the effectiveness of the transformation of the energy sector (Kacprzak et al., 2022).

Another category of resources that plays an important role in the energy sector is financial resources. This sector requires significant investments in both financial and infrastructural areas. This is because most of the energy sector, including in Poland, is owned by large companies with the participation of the State Treasury. As in other European countries, the Polish energy sector takes the form of an energy oligopoly, with participants predominantly producing and distributing domestic electricity. No changes are expected in the coming years in relation to the concentration of capital in the sector. The most relevant regulations for the energy sector are created at the EU and national levels, with project funds distributed top-down among member countries (Lipiński, 2021). The high capital intensity of the sector is also because Poland stands at a crossroads related to the choice of a decarbonisation pathway to reduce greenhouse gas emissions. This path would involve introducing fundamental changes to the current coal-based production structure and shifting the focus towards renewable energy sources. Such changes would require a downsizing of the coal sector, which would translate into significant costs for the economy and society, especially since, in 2021, the sector employed 78 900 workers (Antosiewicz et al., 2020). In addition to the classic ways of financing renewable energy sources associated with EU subsidies, there is also the alternative of crowdfunding, i.e., raising finance for a particular project from private individuals. This is possible because renewable energy sources are often local in nature, which means that local developers, municipalities and residents finance a particular energy installation themselves and become its shareholders (Wojtkiewicz, 2021).

The analysis of the physical resources of the Polish energy sector, particularly the infrastructure, indicates that the Polish energy sector faces significant challenges due to an increase in electricity demand accompanied by a low level and quality of production and transmission infrastructure. A characteristic feature of the Polish energy sector is the specific configuration of the sources from which electricity is generated. Compared to other European countries, Poland is characterised by a high share of coal and lignite. In the context of actions aimed at climate protection and reduction of carbon dioxide emissions, significant investment expenditures are required to reconstruct the production system. In addition, a weakness of the Polish power system is the age of the production units, which are old and have low efficiency or require modernisation or dismantling due to the end of their operational life (Lipski, 2016). Despite the above global trends, in Poland, the main source of stable and continuous energy supply is still coal power plants, and due to a lack of energy storage capacity, their maintenance is becoming a priority issue (Szczerbowski, 2018).

One of the basic types of resources in the functioning of a company in any sector is technological resources, especially in the context of the ongoing fourth industrial revolution related to the process of digitalisation, the implementation of disruptive innovations, automation and the development of communications understood as the use of multiple means of communication (Schaeffer, 2015; Miśkiewicz, 2019). A similar trend is visible in the energy sector, where the consequences of technological change can be observed, despite the industry being considered one of the more resistant to digitalisation processes (Morkisz, 2019; Giones et al., 2019). The use of new technologies enables greater customer focus through the personalisation of products and services using specific technologies, such as the Internet of Things, Big Data analytics, cloud computing, machine-to-machine communication, machine-to-human automation, VR and AR (virtual reality and augmented reality), a simple changeover of production to a variable assortment, and 3D printing (Bašová, 2020).

The energy sector is transforming as new technologies and innovations contribute to changes in existing business models. The global energy industry is shifting from a system based on centralised companies using traditional energy conversion, transmission and distribution technologies towards distributed, digital and low-carbon businesses (Martin et al., 2017). The digitalisation of the energy sector involves many challenges but also creates numerous opportunities. The amount of processed information and the number of performed transactions in the sector is constantly increasing. It is, therefore, necessary to increase the efficiency, transparency, profitability and security of digital platforms in the energy sector. This can be achieved through increased innovation and the development and use of modern tech-

nologies. In addition, digitalisation will enable energy suppliers to establish a direct relationship with the end customer, who will be able to identify intelligent ways to manage their energy resources (Goosen et al., 2020). Other aspects related to the digital transformation process in the energy sector, such as the implementation of integrated smart energy systems, particularly smart information and telecommunications technologies, should also be considered (Voropai, 2020). In conclusion, technological resources are key in transforming the energy sector by increasing efficiency, profitability and security. Therefore, they require continuous investment and development.

A special category within technological resources is information and communication resources. The current dynamic development in this area is changing existing business models and industry ecosystems. This trend is also evident in the energy sector with new emerging services, such as end-to-end inspection, protection and control of energy distribution, and smart consumption, which contribute to the smart grid's management, construction and transformation. With increasing digitalisation, it is necessary to ensure consistency between IT applications and communication technology infrastructures (Sun, 2021). The ICT use in the energy sector can contribute to the transition to a low-carbon electricity system that will enable customers to make more rational energy decisions. A key technology in ICT is the smart meter, which is part of an advanced metering infrastructure that enables the measurement and storage of high-resolution electricity data. This makes it possible to provide data to both consumers and energy companies almost in real-time. The use of this technology enables home energy management, battery management, distributed renewable generation management, demand forecasting and the subsequent reallocation of energy (Yildiz et al., 2017). This can contribute to optimising and increasing the efficiency of household electricity use and, consequently, reducing the carbon footprint of electricity production (Bastida et al., 2019).

1.3. Resource base from the perspective of energy companies' goals

The effectiveness of any company's goals depends, among other factors, on the level and quality of its resources. Depending on the nature of the goals (economic, environmental, social), they will be more or less correlated with the different types of resources (human, financial, infrastructural or technological). The same applies to companies in the energy sector. The question arises as to which resources play a significant role in implementing the goals adopted by companies in the Polish energy sector. To answer this, it is first necessary to identify the goals formulated within this sector.

To implement its climate and energy policy, the European Union imposes an obligation on Member States to reduce and, in the long term, completely abandon coal and lignite as the primary electricity generation source. A pro-ecological solution to this — considering concern for the climate and an attempt to stop global warming — would seem to be investments in renewable energy sources. In light of the United Nations Climate Change Conference findings and the subsequent European Union legal regulations related to reducing emissions of climate-damaging gases, investments in the conventional energy sector development are decreasing significantly (Szczerbowski, 2018). Poland remains one of the few European countries where the importance of coal in the economy is still maintained as a result of political decisions. The Polish energy system requires transformation, the main goal of which should be to reduce the use of coal and ultimately close the mines. These actions should consider economic aspects, such as resources and the profitability of mining, and social aspects in connection with job reductions in the mining sector (Lipski, 2016; Malec, 2022; International Energy Agency, 2022).

In October 2009, the Ministry of National Economy published the Energy Policy of Poland until 2030. Its basic objective, with regard to the production and transmission of electricity and heat, is to permanently cover the demand for electricity, considering the maximum possible use of domestic resources with the application of environmentally friendly technologies. According to the assumptions, this goal is to be achieved, through: (1) the construction of new capacities to meet domestic electricity demand and maintain a capacity surplus from domestic conventional and nuclear generation sources; (2) the development of the national transmission network, which will ensure the reliability of electricity supply, as well as the collection of electricity from areas with a high saturation of planned and newly built generation units, with particular emphasis on wind farms; (3) the development of cross-border connections coordinated with the development of the national transmission network, and with the development of the systems of neighbouring countries (Ministerstwo Gospodarki Narodowej, 2009).

Another document concerning the vision for the energy system development in Poland is the project Energy Policy of Poland until 2050, also developed by the Ministry of National Economy. The main goal formulated in the project concerns the creation of conditions for the energy sector's continuous and sustainable development. This development is necessary for energy security and to meet the energy needs of businesses and households. It is assumed that the above goals will be realised by (1) ensuring an adequate level of generation capacity; (2) diversifying the structure of energy generation; and (3) maintaining and developing transmission and distribution capacities (Ministerstwo Gospodarki Narodowej, 2015).

The above goals relating to the development of the Polish energy sector will first require financial resources to build new and modernise the existing infrastructure (increase the density and modernise the grid and number of transformer stations). In addition, the implementation of the goals will be related to the use of new technologies, the purchase and operation of which will involve further investments. The use of new technologies will depend on having staff with the appropriate skills to use them effectively. This, in turn, generates additional costs associated with developing the competencies of energy sector employees or acquiring new highly specialised staff. In summary, it can be seen that the implementation of the set objectives in the coming years in the Polish energy system will be associated with using all types of resources, but the key role in this aspect is likely to be played by financial resources.

Summarising the considerations in the theoretical background regarding the organisational goals and resources of energy sector companies, it can be noted that although organisational goals relate to different dimensions, such as production, inventory, sales, market share, customer perspective, profitability and sustainability, they are interrelated in some way, forming a coherent set of goals (Kotlar et al., 2018; Lee et al., 2021). Furthermore, it can be assumed that there is a correlation between the possessed resources and the choice and achievement of specific categories of organisational goals (Deligönül & Çavuşgil, 1997). On this basis, the following research hypotheses were formulated:

H1: Different categories of organisational goals of Polish energy companies are interrelated.

H2: Resource types of Polish energy companies determine the choice and achievement of each goal category.

2. Research methods and sample

The paper mainly aimed to identify and assess the resources used to achieve organisational goals in Polish energy companies. The validation procedure described by Fatma et al. (2014) was used to develop a new tool in the form of a questionnaire. The procedure consisted of five following steps.

2.1. First step. Literature review

An in-depth literature review allowed for identifying and defining the importance of the goals and resources of energy companies in Poland. Based on critical literature analysis (Amin & Rahman, 2019; Andoni et al., 2019; Bogomolova et al., 2018; Bryant et al., 2018; Jankiewicz, 2018; Kolk & van Tulder, 2010; Lipiński, 2021; Nogalski et al., 2016a; Parida et al., 2016; Smokvina et al., 2019; Teece et al., 1997; Westerman et al., 2020; Wojtkiewicz, 2021; Wu et al., 2006; Zakrzewska & Gil-Świderska, 2018; Zuppo, 2012), five goal-categories we identified, contributing to the development of the energy sector in Poland: (1) profit maximisation and market share growth; (2) investing in renewable energy sources (RES) and sustainable development; (3) customer perspective: providing the highest possible level of quality of products/services offered, providing customers with products/services at the lowest possible price, ensuring uninterrupted energy supply to customers; (4) implementation of innovative solutions; (5) uninterrupted energy supply and sector development. Also, three categories of resources (human, financial, and infrastructural) were identified to be investigated in the research (Amin & Rahman, 2019; Andoni et al., 2019; Bogomolova et al., 2018; Lipiński, 2021; Smokvina et al., 2019; Teece & Pisano, 1994).

2.2. Second step. Expert survey

In the second step, which consisted of scale development, invited 13 experts were invited, twelve of whom participated in the expert survey. The experts were business practitioners working in managerial and decision-making positions in different energy sector companies. At this stage, the experts suggested that the category of technological resources should be more precise and detailed. Considering

that the research was carried out as part of the Regional Initiative for Excellence programme of the Minister of Science and Higher Education of Poland, at this stage of scale development, six items were excluded, eight items were added, and 19 items were re-formulated.

2.3. Third step. Group discussion

The re-formulated questionnaire was discussed with the group of twelve academic researchers working on energy sector-related issues. After consultations with the academic researchers, who supported the experts in the need to specify technological resources, it was decided to consider "technological resources" in this study under three separate and more specific categories (technological, ICT, and infrastructural resources). Also, the academic researchers encouraged to investigate the organisational goals of energy companies in as much detail as possible. For this purpose, the goal categories were divided into nine different goals. As a result of the discussion, six items were removed from the research questionnaire, and 14 items were re-formulated.

2.4. Fourth step. Pilot testing

In the penultimate stage, four pilot surveys were conducted in 16 companies with a view to ensuring the clarity of the formulated questions. As a result of this step, the whole survey was enriched with three new items, eleven other items were removed, and seven items were re-formulated.

2.5. Fifth step. Main survey

The actual research was carried out as the last part of the scale development process on a sample of 110 companies, including 55 small, 27 medium-sized, and 26 large enterprises.

Statistica software was used to conduct the analyses (descriptive statistics, correlations and cluster analysis). As a final result of the scale development process, the following list of variables was established to be tested in the research (Table 1). The variables are provided with descriptive statistics.

Respondents were asked to choose statements on a 7-point Likert scale (1 — very bad, 7 — very good) corresponding to the degree of importance of achiev-

Tab. 1. Descriptive statistics of variables (n = 110)

Variable	Descriptive statistics					
	Average	Mode	Number of mode	Minimum	Maximum	Standard deviation
Objectives of energy companies						
Sector development	5.54	6	39	1	7	1.44
Profit maximisation	5.54	6	37	1	7	1.35
Market share growth	5.91	6	51	3	7	0.91
Investments in RES	5.35	6	36	1	7	1.45
Quality of products/services	5.80	6	42	3	7	1.03
Low price	5.76	6	50	3	7	0.91
Uninterrupted energy supply	5.68	6	36	2	7	1.09
Implementation of innovative solutions	5.84	6	47	2	7	1.05
Sustainable development	5.76	6	44	2	7	1.01
Organisational resources						
Human resources	5.69	6	42	1	7	1.19
Financial resources	5.63	6	42	1	7	1.15
Infrastructural resources	5.63	6	39	2	7	1.11
Technological resources	5.51	6	40	2	7	1.07
ICT resources	5.38	5	44	3	7	1.03

Tab. 2. Characteristics of the energy companies (n=110)

EMPLOYMENT	NUMBER OF COMPANIES
10 - 49	55
50 - 249	27
>250	28
AGE OF THE COMPANY	**NUMBER OF COMPANIES**
< 2 years	1
2 - 5 years	4
6 - 10 years	27
11 - 25 years	50
> 25 years	28
2 - 5 years	4
6 - 10 years	27
11 - 25 years	50
> 25 years	28

ing the stated goals in their company and to assess the availability of the organisational resources.

The research was performed in June 2021 by a research company. The study used the single-respondent method, and the respondents were managers working in different companies in the energy sector. The competence of the respondents in the field of the research ensured greater credibility and reliability in completing the questionnaires. The research used the computer-assisted web interview (CAWI) method, as this made it possible to obtain a relatively large sample of respondents and, above all, to conduct quantitative research, which was necessary to achieve the aim of the study. Table 2 presents the characteristics of the Polish energy companies studied.

Due to the specific feature of micro-enterprises, i.e., limited human resources, they were excluded from the study. The population of energy sector enterprises in Poland, excluding micro-enterprises, is estimated to be around 180 companies.

3. Research results and discussion

The correlation analysis allowed for concluding that the organisational goals pursued by energy companies are interrelated. Thus, hypothesis H1 was confirmed. The fact that organisational goals are interrelated is not always obvious. For a long time, the theory of management, which is also confirmed by practice, has pointed to the contradiction of goals in the organisation (Rosen, 1970).

First, the study observed that an orientation towards quality assurance is supported by an approach aimed at providing customers with the lowest possible prices. A responsible attitude to pricing by energy suppliers is one of the key areas for implementing a socially responsible strategy. However, the issue of energy pricing is also a challenge in this area. Relatively high energy prices in relation to consumer income limit the ability to engage (for companies) as well as the willingness (for consumers) to pay to engage in renewable energy production or to seek innovation in this area (Campbell, 2007; Pätäri et al., 2014; Weder et al., 2019). Furthermore, Kowal and Kustra (2016) noted that the profitability of Polish energy companies is constrained by relatively low energy prices compared to costs. This study concluded that the aim to ensure the lowest possible prices and quality does not strongly correlate with profit maximisation. The differences in attitudes are also shown by the cluster analysis (Fig. 1). Referring to the issue of pricing and the above discussion; it is also worth noting that the orientation towards RES investment is rather different from the approach to achieving other goals, including those related to pricing policy.

The approach to achieving the goals of implementing innovation most closely coincides with the approach to achieving sustainable development. Mezhner, Tabbara and Al.-Hosany (Mezher et al., 2010) noted that an attitude of social responsibility can play an important role in enhancing the innovative potential of the energy sector. However, Streimikiene, Simanaviciene and Kovaliov (Streimikiene et al., 2009) pointed out that the implementation of sustainable development policies in the energy sector can be hampered by low levels of innovation. The results of this survey suggest that companies in the energy sector in Poland are not currently oriented towards goals in the triad innovation-sustainability-investment in RES. One explanation for the lack of consistency in the activities in these three areas is the traditional nature of the energy sector, based on traditional energy sources (Szczerbowski, 2018; International Energy Agency, 2022), and such a state of affairs calls for in-depth research in this area. Considering the perspective of renewable energy sources seems to be important, as the issue of renewable energy sources is sensitive to aspects of social responsibility (González Ramos et al., 2018).

Hypothesis H2 was also confirmed. Each of the resource categories correlates statistically significantly with the choice and achievement of individual goals (Table 3). The first observation that emerges is about the co-occurrence of the importance of human

resources with an orientation towards sector development (correlation of 0.62), ensuring uninterrupted energy supply (correlation of 0.62), and an orientation towards sustainability (correlation of 0.61). As indicated earlier, insufficient human resources are one of the factors inhibiting the implementation of the concept of social responsibility (Pätäri et al., 2014). Referring to individual objectives covered in the survey, the following observations were made. For the "sector development" goal, only infrastructure resources are below the correlation of 0.5, which may indicate a low level of infrastructure resources, thus requiring significant expenditure on reconstruction and modernisation. Most of the Polish energy sector infrastructure has not been modified since the 1980s and is close to the end of its operational life. The power grid was built to different energy standards than today due to the fact that it was intended for large electricity producers. As a result, energy supply security and transmission grid reliability are becoming increasingly problematic (Jankiewicz, 2018; Zakrzewska & Gil-Świderska, 2018).

For the realisation of the "profit maximisation" goal, financial resources are of key importance, which would seem to be a natural phenomenon; the other resource categories have a relatively weak correlation. The lowest correlation in the ICT resource category (0.27) may result from using modern communication and information technologies and involves investments related not only to the purchase and use of these technologies but also to the need for qualified staff to operate them. Research points to the need to upgrade the skills of energy sector employees in the area of both technical and business skills and to recruit new staff (Černý et al., 2021).

For the "market share growth" goal, human resources (correlation of 0.57) and financial resources (correlation of 0.55) are the most important. For the "investments in RES" orientation, a lower level of correlation was observed with each category of

Tab. 3. Correlation analysis

Variable	Correlation, p-value: p < .05000 n=110													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Sector development	1.00													
2. Profit maximisation	0.49	1.00												
3. Market share growth	0.51	0.49	1.00											
4. Investments in RES	0.40	0.25	0.40	1.00										
5. Quality of products/services	0.49	0.38	0.64	0.40	1.00									
6. Low price	0.59	0.48	0.59	0.34	0.68	1.00								
7. Uninterrupted energy supply	0.58	0.39	0.57	0.36	0.52	0.61	1.00							
8. Implementation of innovative solutions	0,57	0.45	0.66	0.41	0.67	0.68	0.57	1.00						
9. Sustainable development	0.62	0.51	0.63	0.38	0.61	0.63	0.67	0.80	1.00					
10. Human resources	0.62	0.35	0.57	0.40	0.55	0.54	0.62	0.57	0.61	1.00				
11. Financial resources	0.62	0.51	0.55	0.42	0.47	0.55	0.49	0.49	0.52	0.72	1.00			
12. Infrastructural resources	0.46	0.37	0.46	0.36	0.49	0.46	0.36	0.46	0.48	0.62	0.72	1.00		
13. Technological resources	0.56	0.33	0.42	0.34	0.42	0.48	0.44	0.50	0.49	0.72	0.65	0.73	1.00	
14. ICT resources	0.50	0.23	0.40	0.36	0.39	0.44	0.38	0.44	0.46	0.65	0.62	0.65	0.74	1.00

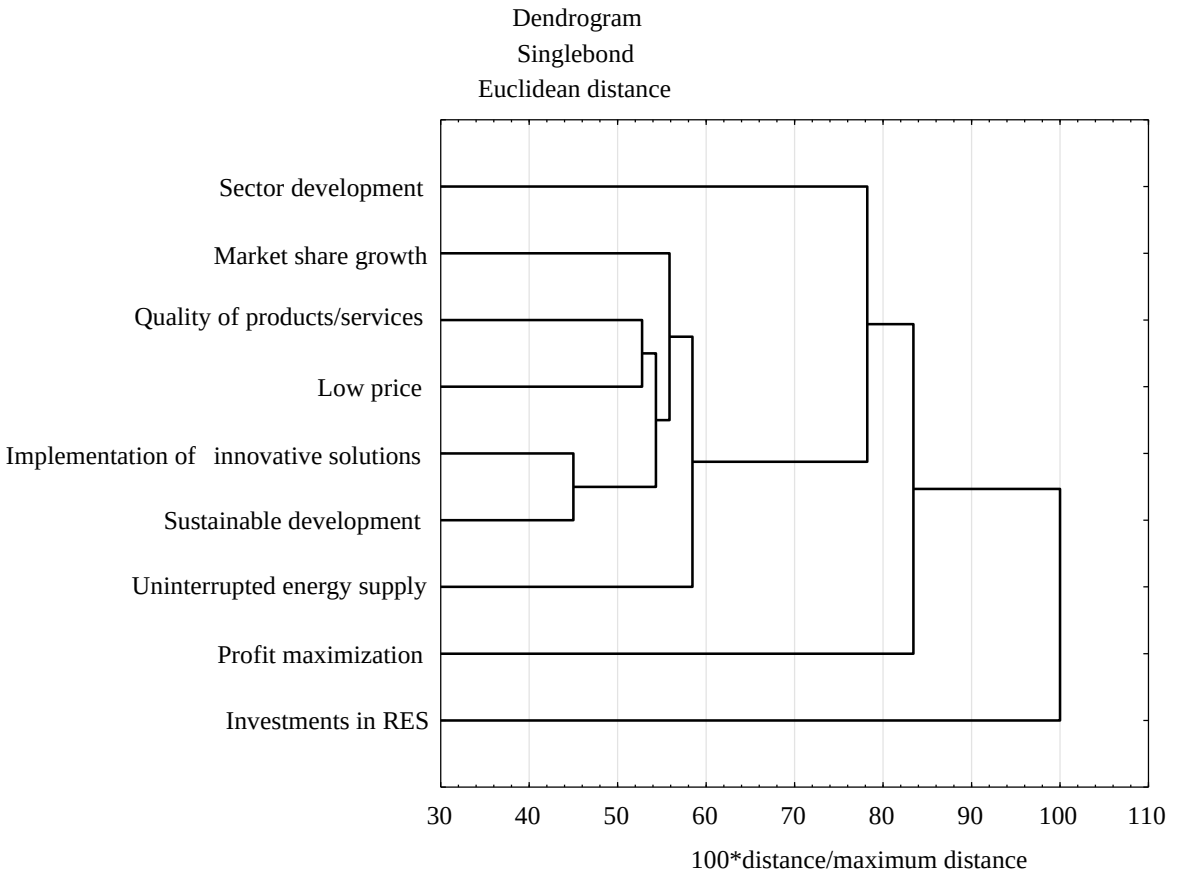

Fig. 1. Cluster analysis for organisational goals of energy sector companies in Poland

resources. On the other hand, for the "quality of products and services", it turns out that human resources are important (correlation of 0.55), which are also relatively strong in relation to the "low price" orientation (correlation of 0.54). In this perspective, a correlation above 0.5 was also observed with the financial resources category (0.55). The category of human resources also appears to be relevant for the other three goals ("uninterrupted energy supply", "implementation of innovative solutions", and "sustainable development"). For the "sustainable development" orientation, a relatively strong correlation is also observed with the financial resources category (0.52).

The cluster analysis (Fig. 1) shows the levels of similarity in the orientation toward the achievement of various goals considered in the research. The chart shows the aforementioned inconsistency of orientation to RES investments.

The highest similarity was observed between the implementation of the goals "implementation of innovative solutions" and "sustainable development" (at levels above 50 %), as well as "quality of product and services" and "low price" (slightly below 50 %). These four goal categories cluster with the "market share growth" and "uninterrupted energy supply" orientations at around 40 %.

Conclusions

The paper aimed to identify and assess the resources used to achieve organisational goals in Polish energy companies. This aim was achieved by answering four research questions at a theoretical and empirical level. The hypotheses formulated in the paper were positively verified.

The analysis of the results concerning the basic organisational goals postulated by Polish energy companies showed that economic goals, such as "market share growth", "implementation of innovative solutions", and "quality of products/services", are at the forefront, which seems justified also for companies in the energy sector (Westerman et al., 2020). Such goals as "low price", "sustainable development", and "uninterrupted energy supply" were rated relatively highly. The least important in the opinion of respondents was the goal related to "investments in

RES", which can be explained by the fact that the basic source of energy production in Poland remains hard coal and lignite. Poland's power plants are still coal-fired and remain a stable source of energy supply. Given the lack of infrastructural possibilities to store energy, the maintenance of conventional sources determines the country's energy security. In the coming years, the Polish energy system will continue to rely primarily on conventional energy, with a growing share of renewable energy sources (Szczerbowski, 2018; Attia et al., 2022).

Regarding the level of resources held by energy companies, human resources received the highest rating. They were followed by financial and infrastructural resources. The lowest ratings were given to the quality and level of technological resources and information and communication technology. This can be explained by the digital transformation process in the Polish energy sector. Notably, the energy sector is extremely resistant to the digitalisation process. Companies in this sector should adapt quickly to the requirements of digital transformation, especially in the case of incumbent companies, for which it can ensure survival. It is postulated that the use of new technologies, including ICT, is an opportunity to guarantee a reliable, resilient, cost-effective and low-carbon energy system (Efimova et al., 2018; Angelopoulos et al., 2019; Morkovkin et al., 2020).

The empirical verification of H1 allows for concluding that the organisational goals pursued by energy companies are interrelated. The analysis of the results showed that the focus on quality assurance is supported by an approach focused on providing customers with the lowest possible price. Maintaining a high-quality energy supply with rising prices is a particular challenge today. However, it should be noted that a responsible attitude among energy suppliers in shaping quality and setting prices is one of the key areas of implementing a social responsibility strategy. In addition, it is worth considering that the very low correlation (0.25) level between RES investment and profit maximisation suggests possible inconsistency between various goals of energy companies. Thus, decisions to invest in RES may not take high priority. Polish energy companies are not oriented towards implementing goals in the triad innovation-sustainable development-investments in RES. This may be because the Polish energy sector is still largely based on conventional and, at the same time, non-renewable energy sources (International Energy Agency, 2022; Szczerbowski, 2018).

The verification of H2 confirmed that the resources held by energy companies are important for implementing separate organisational goals. Human resources are of the greatest importance for implementing the goals of "sector development", "uninterrupted energy supply", and "sustainable development". It is still people, not technologies, that are the initiators of development, and it is their competence that determines the efficiency of operation and the implementation of activities with future generations in mind (Chams & García-Blandón, 2019). The lowest correlation strength of the "sector development" objective is noted with infrastructural resources. This fact can be explained by the outdated condition of the Polish energy infrastructure (Jankiewicz, 2018; Zakrzewska & Gil-Świderska, 2018). Financial resources are key for achieving the "profit maximisation" goal, while ICT resources are the least important. The use of ICT is related not only to the purchase of technologies but, above all, to their use. This generates the need to provide the energy sector staff with digital competences (Smokvina et al., 2019).

It is also important to consider that the business models of energy companies are embedded in the legal framework of the economies in which they operate (Burger & Luke, 2017). Consequently, the goals of energy companies appear to some extent to be derived from the past decisions and directions of individual entities.

The main study's contribution is the highlighted meaning of resources for achieving organisational goals in Polish energy companies. Expanding knowledge in the field of the resources required for the implementation of organisational goals brings added value not only for the development of management and quality sciences but also for business practice. For managerial practice, it is also important to define the links between the individual goals of companies in the energy sector.

This research has several limitations; however, these limitations may become the basis for further research. The limitations of the research procedure can be reduced to four basic issues. First, adopting the single-respondent method in research increases the likelihood of subjectivism bias. Therefore, it would be worth inviting several respondents from each entity. In this way, the perspective of the researched problem could be broadened. Second, the study was conducted on small, medium-sized and large energy companies. Although the study assumed that micro-entities should be excluded due to their specificity of resource

management, the inclusion of micro-enterprises in the study could have provided a fuller picture of energy companies' goals and resources across the sector. Third, research on organisational goals that fit into the contemporary business models of energy companies requires a deeper and broader insight into individual categories of resources. Fourth, the specificity of management in the energy sector is conditioned by political and economic decisions. Hence, this research may be biased by the conditions prevailing in the Polish economy. It would be worth conducting similar research in the energy sector of other countries to gain a broader, international perspective and capture possible differences.

Acknowledgment

The project is financed within the Regional Initiative for Excellence programme of the Minister of Science and Higher Education of Poland, 2019-2022, grant No. 004/RID/2018/19, financing of PLN 3 000 000.

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sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 2 April 2023
accepted: 31 July 2023

pages: 69-83

Industry 4.0 technologies and managers' decision-making across value chain. Evidence from the manufacturing industry

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ABSTRACT
The paper aims to identify how Industry 4.0 technologies affect the quality and speed of the managers' decision-making process across the different stages of the value chain, based on the example of the manufacturing sector. The paper adopts qualitative research, based on nine in-depth interviews with key informants, to capture senior executives' experiences with implementing Industry 4.0 technologies in their organisations. The research is focused on three manufacturing industries: the automotive, food and furniture industries. The research shows that depending on the stage of the value chain, different Industry 4.0 technologies are more suitable for the support of managers' decisions. Various Industry 4.0 technologies support decision-making at different stages of the manufacturing value chain. In the Design stage, 3D printing and scanning technologies play a crucial role. In the case of Inbound Logistics, robotisation, automation, Big Data analysis, and Business Intelligence are most useful. During the Manufacturing stage, robotisation, automation, 3D printing, scanning, Business Intelligence, cloud computing, and machine-to-machine (M2M) integration enable quick decision-making and speed up production. Sensors and the Internet of Things (IoT) optimise distribution in the Outbound Logistics stage. And finally, Business Intelligence supports decisions within the Sales and Marketing stage. It is also the most versatile technology among all particular stages. The paper provides empirical evidence on the Industry 4.0 technology support in decision-making at different stages of the manufacturing value chain, which leads to more effective value chain management, ensuring faster and more accurate decisions at each value-chain stage. When using properly selected Industry 4.0 technologies, managers can optimise their production processes, reduce costs, avoid errors and improve customer satisfaction. Simultaneously, Industry 4.0 technologies facilitate predictive analytics to forecast and anticipate future demand, quality issues, and potential risks. This knowledge allows organisations to make better decisions and take proactive actions to prevent problems.

KEY WORDS
Industry 4.0, decision-making, value chain, technologies, manufacturing industry

10.2478/emj-2023-0021

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Introduction

Decision-making is one of the most important daily activities in companies. The decision-making process is a logical sequence of activities. It can be defined as an outcome of evaluation processes leading to determining the most appropriate choice among several alternatives (Kaya & Kahraman, 2010), which should result in the highest success probability or greatest effectiveness. Accurate decisions should lead to high company performance (Shepherd et al., 2021); therefore, companies strive to obtain the best real-time data and create decision-support systems

Młody, M., Ratajczak-Mrozek, M., & Sajdak, M. (2023). Industry 4.0 technologies and managers' decision-making across value chain. Evidence from the manufacturing industry. *Engineering Management in Production and Services, 15*(3), 69-83. doi: 10.2478/emj-2023-0021

(Villalobos et al., 2019). Making accurate, fast and high-quality decisions is even more important in a dynamic, uncertain and turbulent environment. In this regard, digitisation and modern technologies can significantly facilitate the decision-making process (Ali & Kumar, 2011; Darwish et al., 2014; Wieder & Ossimitz, 2015; Janssen, van der Voort & Wahyudi, 2017). The much-discussed technologies include Industry 4.0 (I4.0), i.e., the Internet of Things (IoT), cloud computing, automation and advanced robotics, 3D printing and scanning, information and communication technologies solutions (ICT), as well as Business Intelligence (BI) systems, augmented reality (AR) and virtual reality (VR) (Henke & Wilmott, 2018). The development of such technologies enables the faster introduction of new products, sales via many different sales channels, and a rapid response to customer and market needs (Cañas et al., 2021). These should lead to a competitive advantage based on increased value for the customer while reducing costs. The typical manager's role will not be altered by Industry 4.0; however, the tools and techniques utilised to fulfil these management activities will change (de Sousa Jabbour, 2018; Pozzi et al., 2023; Ribeiro et al., 2021).

A helpful method for seeking a competitive advantage in particular processes and activities is value chain analysis, understood as a group of vertical activities that can add value to goods or services in the process from raw material to a finished product that is supplied to the consumer and/or end-user organisation (Simatupang, Ginardy & Handayati, 2018). At each value chain stage, managerial decisions are made, the consequences of which impact company effectiveness and competitive advantage. Porter (1999) indicated that information technology (IT) impacts how companies operate, leading to differentiation and cost reduction. Since then, value chain analysis has explored the strong linkage between information, material and fund flows with technologies, as well as constant progress towards adopting digital technologies (Núñez-Merino et al., 2020).

Studies show that in value chain analysis, particular technologies, such as RFID (Radio-Frequency Identification) and IoT, provide economic benefits to the business (Unhelkar et al., 2022) and impact operational performance, productivity and high visibility across multiple processes (Gomes et al., 2022). However, there is a lack of detailed research indicating which technologies support managerial decisions at various stages of the value chain.

As far as decision-making is concerned, there are studies on the impact of Industry 4.0 technologies on support of managerial decision-making (Wieder & Ossimitz, 2015; Janssen, van der Voort & Wahyudi, 2017; Neziraj & Shaqiri, 2018), but they do not discuss in detail the particularities of the value chain. Furthermore, there are studies relating to the digital transformation's impact on reshaping the manufacturing industry value chain (e.g., Savastano & Amendola, 2018), but they do not discuss the specifics of the decision-making process. Therefore, there is no information on which Industry 4.0 technologies support managerial decisions made at subsequent value chain stages, particularly regarding the speed and quality of decisions. These factors are extremely important for creating value at every stage of the chain. The stated research gap is valid as particular stages of the value chain, due to their specificity, require different decisions supported by different I4.0 technologies affecting the created value and competitive advantage. It can also be assumed that the variety of decisions within different value chain stages determines the variety of useful technologies. This leads to the question of how and to what extent different Industry 4.0 technologies support decision-making at particular value chain stages.

Thus, the paper aims to identify how Industry 4.0 technologies affect the quality and speed of the decision-making process across different value chain stages in the manufacturing sector. To achieve this aim, the paper presents qualitative research results based on the interview method with key informants (Alvesson & Lee Ashcraft, 2012). The interviews were conducted in the manufacturing sector. There are two major reasons behind this choice. First, this is an industry with widely implemented advanced Industry 4.0 technologies, enabling companies to produce smarter, faster and more effectively (Mehta, Butkewitsch-Choze & Seaman, 2018). Second, value chain analysis, inherent in the manufacturing sector (Nauhria, Kulkarni & Pandey, 2018), enables for tracking of the new technologies' impact on the quality and speed of decision-making in particular stages, which is crucial for the entire process of creating value for the customer. The analysis of how the technologies facilitate managerial decisions at every stage of the value chain allows for the identification of technologies that have an impact on the quality of decisions and their speed, and sometimes even complete elimination of the decisions themselves (decisions can be made autonomously by algorithms), creating value and leading to a competitive advantage.

This paper makes two main theoretical and practical contributions. First, it provides evidence that various Industry 4.0 technologies facilitate decision-making at different stages of the manufacturing value chain. In particular, the technologies' impact on the quality and speed of the decision-making process was examined. Second, knowledge about technology support leads to more effective value chain management. Particular technologies that speed up and/or improve the quality of decisions made by managers enable a value increase at each value chain stage. Faster and more accurate decisions allow for creating a competitive advantage over companies that do not have such support.

Following this introduction, the paper is structured as follows. First, the importance of the decision-making process across the value chain and the scope of I4.0 technological support for managerial decisions are discussed. Next, the research methodology is presented, the main findings of the research are analysed, and the main conclusions are drawn.

1. Literature review

1.1. Decision-making process across the value chain

Decision-making is a process of choosing from several alternatives to achieve a desired result (Eisenfuhr, 2011). It involves several interrelated stages, including identifying the problem, generating alternatives, evaluating alternatives, choosing an alternative, implementing the decision, and evaluating the decision's effectiveness (Lunenburg, 2010; Darwish et al., 2014). The definition of the decision-making process emphasises three key elements. First, decision-making involves choosing from several options; second, it is a process that involves more than a simple final choice among alternatives; and finally, the mentioned "desired result" involves a purpose or target resulting from the mental activity of a decision-maker to reach a final decision.

Information is among the most important factors in management decisions. Having detailed, accurate and timely information accelerates decision-making and prevents wrong decisions (Darwish et al., 2014). This is even more important considering the ever more uncertain business environment, which makes the decisions more risky, complex and demanding. Given that the decision result affects the success, failure and outcome of the organisation's future condition, the decision maker is expected to make fast, accurate and high-quality decisions. To avoid mistakes and errors, better decisions should be based on knowledge, experience, intuition, goals, diligence and more information to ensure better results (Neziraj & Shaqiri, 2018).

Rapid innovation, shortened product life cycles and fierce competition place great pressure on managers to make fast strategic decisions (Shepherd et al., 2021). Several factors influence the speed of strategic decisions: extensive analysis, power centralisation and conflict trigger interruptions in the decision process (Zehir & Özşahin, 2008). Fast decision-making is important in creating value for customers and gaining an advantage over competitors. To drive effective adaptation, decisions must be made quickly enough to keep up with changing external environment (Clark & Maggitti, 2012). Hence, decision speed is a key source of competitive advantage, enabling firms to respond rapidly to rivals' competitive moves and capitalise on emerging opportunities before they disappear (Shepherd et al., 2021).

Besides speed, decision quality is the other key aspect of decision-making research. It is based on information quality (Wieder & Ossimitz, 2015). Furthermore, there is an emphasis on the validity of the quality of the data and information that will serve as a basis for decision-making (Neziraj & Shaqiri, 2018). Raghunathan (1999) defined decision-making quality as the accuracy and correctness of decisions. Decision quality may improve or degrade when information quality and its processing improve (Raghunathan, 1999). As Wieder and Ossimitz (2015, p. 1165) indicated, "information reduces uncertainty for the decision-maker by assisting in the identification of the alternatives available, and/or by predicting the consequences of selecting an alternative". Prior studies show that the decision quality depends on the quality of the inputs and the process that transforms the inputs into outputs (Janssen et al., 2017). However, it must be noted that the quality and speed of the decisions are relative terms that may be assessed subjectively after the decision is made. In other words, whether the decision was of high quality and fast enough is assessed based on the results obtained from this decision (Gomes et al., 2022).

Decisions can be analysed from the value chain's perspective as this approach enables the assessment of the impact of decisions on the value creation in individual value chain stages. A value chain, a concept developed by Porter (1985), has become a tool for understanding how companies can create and sustain

value for their customers and how to maximise it. A value chain is formed by several generic categories of primary activities (i.e., Inbound Logistics, Operations, Outbound Logistics, Marketing and Sales, and Service) and support activities (including the firm's infrastructure, human resources management, technology development, and procurement), which are useful in delivering valuable products or services to the market. At each value chain stage, managers make decisions aimed at maximising the created value and delivering it as quickly as possible. Value is an aggregation or a bundle of benefits added at every stage of the process, meaning that each activity has its unique value-added element (Simatupang et al., 2018). Research shows that this value is determined by the speed and quality of managerial decisions, especially since the external environment is complex and multidimensional (Bradley et al., 2011; Rosenbusch et al., 2013; Elbanna et al., 2020), and delivering this value is critical to customer satisfaction and a company's competitive advantage.

Although the concept introduced by Porter (1985) has been modified by other authors (e.g., Simatupang et al., 2018), including the innovation value chain (Hansen & Birkinshaw, 2007), the shared value chain (Porter & Kramer, 2011), and the design-driven innovation value chain (Verganti 2009), the traditional Porter's value chain framework is the most suitable approach for the analysis of physical goods and manufacturing industry.

The analysis of decision-making problems is extensively studied in academic literature, primarily because of the increasing significance of efficiency and the imperative to achieve optimal outcomes for businesses (e.g., Cui et al., 2021; Gomes et al., 2022). Similarly, value chain analysis is a commonly employed method for assessing the value generated by companies. Nonetheless, there is a lack of research that integrates the decision-making analysis across different value chain stages, particularly concerning the speed and quality of decision-making. This is particularly important in the current era of digital transformation within companies, which necessitates faster decision-making and the continual elimination of managerial mistakes.

1.2. Scope of I4.0 technological support for managerial decisions

In the era of the ongoing Fourth Industrial Revolution, also known as Industry 4.0, the digital and physical worlds are converging (Pham et al., 2019). So-called "general purpose technologies" (or "founding technologies"), usually perceived as a computer, the Internet and a smartphone (Jovanovic & Rousseau 2005), continue spreading to all economic sectors. However, there are also some disruptive technologies that have the greatest potential to upend the way the economy and society currently function. These technological solutions, referred to as Industry 4.0 (I4.0) technologies, include the Internet of Things (IoT), machine-to-machine (M2M) solutions, cloud computing, automation and advanced robotics (AAR), 3D printing and scanning, ICT solutions, and Business Intelligence (BI) systems (Henke & Wilmott, 2018). Similarly, Kearney (2020) perceived I4.0 as an ecosystem of five fundamental technologies: (1) artificial intelligence (AI), (2) the IoT, (3) 3D printing, (4) advanced robotics, and 5() wearables, augmented reality and virtual reality. Additionally, automated machine learning, quantum computing and 4D printing should also be listed among I4.0 technologies, even if the development of these solutions is still in the early stages (Kearney, 2020). The list of technologies is open because of continuous rapid development across various industries spending funds on research and development.

Technological advancement, including I4.0 technologies, creates a challenge to companies (Sousa et al., 2020) while facilitating their performance and development (Dalenogare et al., 2018; Hofmann & Rüsch, 2017; Liao et al., 2017; Robert et al., 2020). Companies can obtain various advantages depending on their level of technological readiness for Industry 4.0, their capacity to analyse data in real-time (Abdelmajied, 2022) and a general increase in their organisational efficiency (Stouthuysen, 2020; Oláh et al., 2020). To identify and comprehend the changes that must be made to maximise the benefits of I4.0 technologies, it is necessary to investigate the link between technologies and their use in decision-making processes.

The early I4.0 information technologies already played an important role in the decision-making process (Porter, 1985). Even more so today, in times of rapid changes and difficult competitive conditions, new technologies, including those of I4.0, improve the decision-making process by accelerating it and providing the necessary information in real-time (Neziraj & Shaqiri, 2018). As data becomes larger, more complex and more inexplicable, the limited mental capacities of humans pose difficulties in interpreting an unknown environment (Janssen et al., 2017), and this is where advanced Big Data technolo-

gies are greatly needed. Other positive effects arising from new technologies in the decision-making process include enabling the development and emergence of new tools tailored to the requirements of decision-makers, an increase in success in decision-making, and the ability to use stored data and information (Darioshi & Lahav, 2021; Gattiker & Goodhue, 2002; Loderer et al., 2020).

Several technologies and digitalisation solutions support managerial decision-making in the age of Industry 4.0, part of which may be supported by, e.g., computers, smart apps and advanced algorithms. The advancement of manufacturing systems necessitates faster and higher-quality decisions. Much more data is accessible than previously as systems organising and assessing the data and the parameters acquired from production provide efficient assistance to management in decision-making. The latest research emphasises the potential of one or more technologies to improve specific stages of the decision-making process. The proposed decision-making models are partly based on Industry 4.0 technologies, such as BD and AI (e.g., Kościelniak & Puto, 2015; Zolotová et al., 2020; Toušek et al., 2022), focusing primarily on operational assistance or concern autonomy in strategic decisions.

As Rosin et al. (2022) pointed out, managers appear to be anticipating the improvement of task-centred autonomy by Industry 4.0 technology. In this regard, managers' expectations seem to lead to substantial agreement on the amount of improvement provided by Industry 4.0 technologies in terms of governance autonomy. The influence of Industry 4.0 on the decision-making process has thus far been limited to the many decision-making tasks rather than the process as a whole (Ansari et al., 2020). Castelo-Branco et al. (2022) identified conditions conducive to the successful implementation of Industry 4.0 and looked for implications within the value chain from the smart factory through the value proposition to customer experience. They devised a model that considers the above-mentioned manifestations of Industry 4.0 along the value chain, which should be analysed in an integrated manner. Similarly, Schumacher et al. (2016) took the view that there are some organisational areas of the value chain that are affected by Industry 4.0 through strategy, culture, human resources and processes. Some authors focused on specific industries, e.g., Müller et al. (2019) stated that Industry 4.0 applications can be identified along the entire wood supply chain, and Bastug et al. (2020) explored Industry 4.0 applications utilised by seaports through website content analysis. However, to the best of the authors' knowledge, there is no research considering the opportunities provided by the collaborative contribution of specific Industry 4.0 technologies to the decision-making process across the whole value chain. Integrating these two areas is crucial for understanding the evolving competitive advantage sources.

2. Research methodology

2.1. Method

The paper adopted qualitative research based on the interview method (Alversson & Lee Ashcraft, 2012) to find and characterise new concepts, categories or relationships, which is especially important when a new phenomenon is under research, and there are insufficient explanations of a specific situation (Graebner et al., 2012). Additionally, such research is particularly suitable for understanding how such processes as decisions happen (Marschan-Piekkari & Welch, 2004). The research procedure (Fig. 1) covered nine steps and was consistent with the qualitative approach commonly used in social sciences (Symon & Cassell, 2012).

In-depth interviews were conducted to capture senior executives' experiences with implementing Industry 4.0 technologies in their organisations. The fundamental advantage of conducting in-depth interviews is that they foster an open environment, which aids in the problem examination from a wider viewpoint (Curasi, 2001). An interview scenario was created focusing on open-ended questions encouraging a discussion.

The main questions that were asked during the interview were about the types of I4.0 technologies adopted by the company across the whole value chain and the assessment of their positive (or negative) impact on the company's operation in general, and on the speed and quality of managerial decisions in particular.

During the interview, a 4.0 technology catalogue was used that included the following technologies: Big Data, 3D printing and scanning, virtual and augmented reality, IoT, M2M, blockchain, cloud computing, digital twins, RFID, automation and advanced robotics, smart sensors and wireless transmitters, Business Intelligence solutions (the list prepared based on Bartodziej, 2017; Hermann et al., 2016; Kearney, 2020). However, the authors remained open

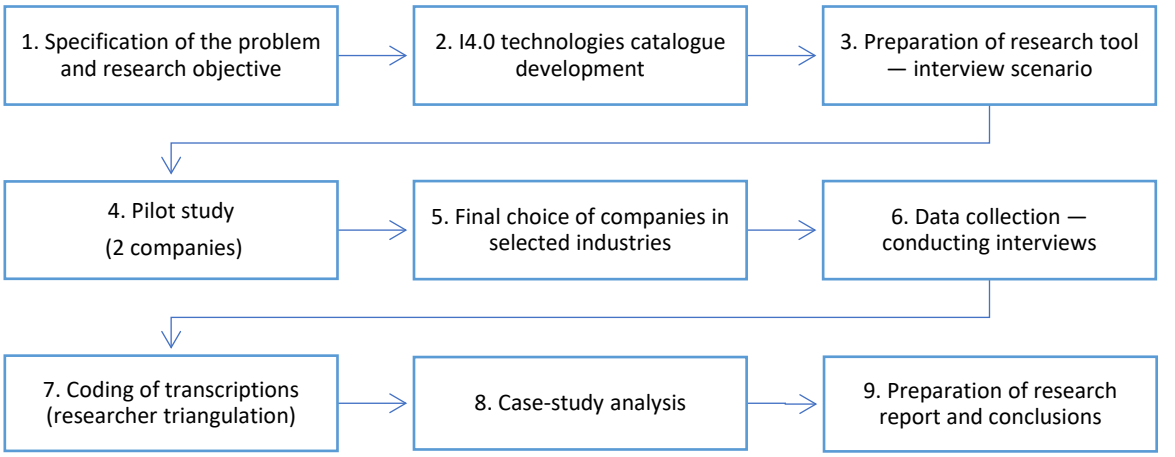

Fig. 1. Research design

to new technologies indicated by the interviewees. In this case, e.g., intelligent applications technology was added to the original list.

2.2. Data collection

In general, the adoption of Industry 4.0 technologies in Polish enterprises is rather slow (when compared to highly developed economies) due to several hurdles to their implementation. Thus, for several reasons, this research focused on three selected manufacturing industries: the automobile, food and furniture industries. First, these industries have embraced digital transformation and use I4.0 technologies in various ways (e.g., Konur et al., 2021; Yasin et al., 2021). The manufacturing industry widely utilises advanced I4.0 technologies, which help companies produce goods more efficiently and effectively. Second, these industries are critical to the Polish economy, forming an important part of the manufacturing industry (Statistics Poland, 2022). Besides, value chain analysis is an integral part of the manufacturing industry, allowing for the measurement of the impact of new technologies on decision-making speed and quality at specific stages of the production process (Nauhria et al., 2018). This is essential for creating value for customers.

A purposeful sampling of companies was employed. These companies were selected based on respective industries' reported maturity in adopting I4.0 technologies (according to The Smart Industry Readiness Index (SIRI) 2020). In other words, the assumption was that the analysed organisations were experiencing or had undergone technology 4.0 deployment across at least some parts of the organisation.

The study was carried out in June–August 2021 among senior managers responsible for Industry 4.0

Tab. 1. Company characteristics

INDUSTRY	COMPANY	YEAR OF ESTABLISHMENT	MAIN PRODUCTS	EMPLOYMENT	REVENUE (MILLION EUR)
FOOD INDUSTRY	Alpha	1993	Dairy products	800	149
	Beta	2012	Fruit and vegetable juices	350	115
	Gamma	1990	Diverse assortment of products	n/a	1 300
FURNITURE INDUSTRY	Zeta	2002	Furniture	100-250*	2,1
	Eta	2014	Furniture	100-250*	28
	Kappa	2006	Furniture	100-250*	148
AUTOMOTIVE INDUSTRY	Lambda	2004	Automotive parts	220	32
	Sigma	2003	Automotive parts	1900	301
	Omega	2007	Automotive parts	730	41

* Note: precise data unavailable

technology implementation and representing five large (over 250 employees) and four medium-sized companies (50–249 employees). Selected characteristics of the companies, i.e., year of establishment, revenue, employment and main products, are presented in their responses. It was also determined by the time frame available to the managers for the interviews. The interviews were recorded and then transcribed.

The interviews were performed remotely due to the restrictions imposed by the Covid-19 pandemic. The overall time of all the interviews was 15 hours and 45 minutes, with each interview lasting an average of 105 minutes. The longest interview lasted over two hours, while the shortest lasted only 55 minutes. The duration of the interviews was caused by disparities in the respondents' approaches and openness.

2.3. Data analysis

Two researchers analysed the transcripts independently to confirm the reliability and validity of the results' interpretation (researcher triangulation). The researchers created and then used a code book and a catalogue of perceived I4.0 technologies.

To identify particular stages of the value chain, Porter's value chain (1985) framework was adopted, which is particularly useful for analysing the manufacturing industry and physical goods when focusing on corporate areas with a primary role in customer value creation. The analysis considered only generic categories of primary activities, as their role is crucial in creating added value. These included project/design, inbound logistics, manufacturing, outbound logistics, and sales and marketing. The authors were aware of the importance of the support activities involved in sustaining the primary activities, but as they were often fully outsourced, an analysis based on the interviews proved incomplete. Similarly, customer service/post-sales activities were excluded as no impact of 4.0 technology was identified. At the same time, the investigation was expanded to include a project/design stage, which significantly impacts the final value creation. As business process digitalisation is gradually reconfiguring every aspect of operating and organisational activities along the entire value chain (Savastano et al., 2018), the partially followed idea was "the innovation value chain" proposed by Hensen and Birkinshaw (2007), who perceive the design stage of the value chain as crucial ("primary") for a company's success. The stages of the value chain were directly declared by the respondents who, while discussing the impact of the I4.0 technologies, described the decisions and defined the stage of the value chain at which they were made.

As far as the identification of technologies and value chain activities are concerned, in most cases, they were mentioned directly during the interviews. A similar approach was used for the indicated support for decision speed and quality. The interview focused on the impact of technologies on the speed and quality of decisions. The decision-making speed was defined as the time necessary to make a decision or even transfer the decision-making to intelligent or automation systems. The decision-making quality was defined based on Raghunathan (1999) as the accuracy and correctness of decisions and the compliance of the achieved effects with the assumed goals. Decision speed and quality were assessed subjectively by the respondents.

3. Research findings

All the analysed manufacturing industry companies use I4.0 technologies to some extent, facilitating managerial decisions. Table 2 summarises the research results in terms of I4.0 technologies applied by these companies and the declared impact of the technologies on the speed and quality of managers' decisions within particular stages of the value chain. The subsequent analysis is conducted sequentially on successive stages of the value chain and focuses mostly on the chosen individual technologies and their impact that was mentioned repeatedly by more than one analysed business entity.

Design plays a growing role in so-called "input activities". Competition is fierce, and with unified products in terms of quality (the same sub-suppliers), the design stage plays a key role in creating value. At the project/design stage, decisions focus on correct planning and adapting the product to the customer's needs as quickly as possible. Almost all analysed companies use 3D printing and scanning to design prototypes and quickly create an offer for customers. As one of the managers exemplifies: "This greatly shortens the design process because previously we collected the dimensions in traditional form and now we take a photo, and after a while, we have a model in the design program for 3D printing" (Lambda). Additionally, this technology allows for faster verification of product concepts: "We use 3D additive printing technology mainly for prototyping and test-

Tab. 2. Identified I4.0 technologies and the quality and speed of managers' decision-making across the value chain — research results

VALUE CHAIN		PROJECT/DESIGN		INBOUND LOGISTICS (E.G. SUPPLIER MANAGEMENT, WAREHOUSING)		MANUFACTURING		OUTBOUND LOGISTICS (WAREHOUSING, DISTRIBUTION)		SALES AND MARKETING	
INDUSTRY	FIRM	SPEED	QUALITY	SPEED	QUALITY	SPEED	QUALITY	SPEED	QUALITY	SPEED	QUALITY
FOOD	ALPHA					Automation of production decisions — fast validation of materials and finished products (3D scanning)	Elimination of production errors resulting from wrong decisions (3D scanning, smart sensors IoT/M2M)				
	BETA	Designing prototypes and creating an offer for customers in a short time (3D printing)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing)					Faster identification and elimination of errors in logistics (automation & robotisation)	Identification and elimination of errors in logistics (automation & robotisation)		
	GAMMA	Fast decisions based on real-time data analysis (Business Intelligence)	Support for innovation decisions based on research (Big Data)	Support for decisions on warehousing — autonomous storage (automation & robotisation)	Process planning support (smart sensors and transmitters). Support for decisions by limiting errors in the product flow (Business Intelligence)	Faster reaction to production errors — predictive maintenance (IoT/M2M) Acceleration of reaction to market changes — just-in-time manufacturing (Business Intelligence)			Distribution decision support based on real-time sales data (IoT/M2M)		Marketing decisions based on precise sales data (M2M/IoT). Support for decisions on sales forecasting, customer segmentation and offer personalisation (Big Data/Business Intelligence)
FURNITURE	ZETA	Designing prototypes and creating an offer for customers in a short time (3D printing/scanning)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing/scanning)			Increasing the flexibility of production decisions — personalisation of products (3D printing)					
	ETA	Designing prototypes and creating an offer for customers in a short time (3D printing/scanning)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing/scanning)			Shortening and automation of production decisions (automation & robotisation)					Support for decisions on offer personalisation and customer relationships (smart apps/virtual solutions)
	KAPPA	Designing prototypes and creating an offer for customers in a short time (3D printing/scanning)		Support for decisions on warehousing — autonomous storage (automation & robotisation)		Faster production decisions based on a smooth information flow (Business Intelligence).					Support for decisions on sales forecasting, customer segmentation (Business Intelligence)

Value chain		Project/design		Inbound logistics (e.g. supplier management, warehousing)		Manufacturing		Outbound logistics (warehousing, distribution)		Sales and marketing	
Industry	Firm	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality
						Automation of production decisions — full integration of the production system (M2M)					
Automotive	Lambda	Designing prototypes and creating an offer for customers in a short time, faster adaptation of a product to customer requirements & faster decision to accept the order (3D scanning)					Elimination of production errors resulting from wrong decisions (automation & robotisation)			Acceleration of the sales cycle and customer service time (Business Intelligence)	Support for decisions on sales forecasting, customer segmentation, promotional activities (Business Intelligence)
	Sigma	Designing prototypes and creating an offer for customers in a short time; faster verification of product concepts (3D printing/scanning)	Facilitating decisions on designer review — evaluation and verification of projects (virtual solutions)	Accelerating logistics decisions in terms of supplier management (Big Data)		Faster decision-making based on quick access to data and reports (cloud computing)	Elimination of production errors resulting from wrong decisions (IoT)		Estimating logistics parameters — simplification of decisions at the board level (Business Intelligence)		Facilitating decisions on customer relationship management (Business Intelligence)
	Omega	Designing prototypes and their verification in products in a short time (3D printing)	Facilitating decisions on the flexible adaptation of the offer to market needs (3D printing)		Facilitating decisions on warehouse management - pursuing rights with component suppliers. (Big Data)	Autonomation of production decisions			Facilitating analysis and decisions on the evaluation of the logistics process (Business Intelligence)		

ing concepts that we cannot directly implement with the use of final products, due to the cost and time of production" (Sigma), and in particular it allows for faster adaptation of a product to a customer's requirements: "We have 3D printers to build bottle prototypes to show the customer a visualisation of what it might look like in the future (...). The customer expects it to be implemented quickly" (Beta).

Although the respondents focused on the decision-making speed as a positive effect of 3D printing, it can also be linked at least partly to the quality of these decisions. Being able to quickly test a concept or visualise an idea allows for the avoidance of errors at the stage of creating a project and product concept. As one of the managers points out: "We use 3D printing at the level of furniture design because it is quite simple; you can imagine things and implement projects quite quickly" (Eta). This is especially important in the case of products tailored to individual needs (e.g., custom-made furniture), where the use of 3D printing at this stage allows for more effective cooperation with the customer, thus avoiding wrong decisions and reducing unnecessary costs ("Now, we model the first models in 3D and ship them to the customer. If the customer intends to make some changes, we introduce changes to the virtual model" (Zeta). This quality of decisions in terms of innovations introduced to products is also facilitated by Big Data analysis, which is described as "a concept trigger" (Gamma).

The decisions within the next stage of the value chain, namely, Inbound Logistics, tend to be speeded

up thanks to the robotisation and automation applied in warehouses, and thus, the introduction of autonomous storage decisions: "We have high storage systems, where everything is automatically placed and then picked, thanks to which the completion of shipments is automatic" (Gamma). At the same time, this automation of warehouses not only speeds up or rather eliminates managerial decisions but also leads to cost-effectiveness ("it accelerates everything, it also increases our bargaining power during discussions with suppliers" (Kappa)). As far as the quality of decisions at the stage of Inbound Logistics is concerned, the respondents tended to underline the influence of I4.0 technologies on limiting errors and facilitating quality control. In particular, this concerns collecting data and, thus, controlling the quality of components and raw materials thanks to Big Data analysis, eliminating errors in deliveries and product flow obtained via Business Intelligence, and the quality control of supplies in comparison to a 3D template.

Manufacturing in the value chain concerns the transformation of input into the final product. The speed of managerial decisions concerning manufacturing is facilitated by the diversity of I4.0 technologies. First, robotisation and automation allow for the autonomation of production decisions and even eliminate the involvement of managers in some production processes, as one of the respondents exemplified: "We have made a system that makes automatic decisions. It is about the process of access control and making decisions about how to classify the finished product after testing. The system makes this decision and analyses all the samples, assigns the appropriate class and inserts it into the system and marks this batch. (…). In this way, the human has been completely eliminated from the process" (Alpha). The aim to limit the involvement of people at the production stage and, thus, their decisions was underlined by several respondents (Zeta, Omega). The automation and speed of production decisions are also facilitated by 3D printing and scanning, which allows for fast validation of materials and finished products, while Business Intelligence and cloud computing provide a smooth flow of information and quick access to data and reports, as well as M2M and full integration of the production system.

I4.0 technologies enable managers to react quickly to emerging changes and eliminate errors, which is linked to the quality of decisions. The IoT and M2M allow for so-called predictive maintenance, meaning managers react faster to production errors ("The use of the Internet of Things and M2M communication as part of predictive maintenance and failure prevention, makes employees react earlier and does not result in major repairs" (Gamma)). These errors are also mitigated by 3D printing and scanning, robotisation and automation, and the use of sensors and IoT.

Regarding Outbound Logistics, including warehousing and distribution of finished products, the respondents focused on the supportive role of I4.0 technologies in terms of decision quality. Mostly, this concerned Outbound Logistics evaluation and control facilitated by Business Intelligence, IoT and M2M and was linked with the identification and elimination of errors in logistics provided by robotisation and automation. As one of the managers described: "We use the Internet of Things, e.g., in logistics to track transports, shipments (…) because we have noticed that in many cases strange things happen to the shipment, and then there is confusion about the reasons. So, we install special sensors that collect this data and, at the same time, send information that is analysed on an ongoing basis. (...) Wireless transmitters in conjunction with Big Data, Business Intelligence, and the Internet of Things and machine communication play an important role here" (Sigma). The same technologies, i.e., IoT and M2M, facilitate the distribution of products based on real-time sales data. The same respondent added: "M2M communication with external systems allows us to determine the consumption of warehouse demand, which affects the operation of these warehouses and stock levels. Business Intelligence, through the use of intelligent sensors in transport, allows us to estimate delivery times, delivery costs, the current location of given components and the demand for them and optimises the entire logistics process" (Sigma).

Sales and Marketing, the final analysed value chain stage, is linked with advertising, promotion, and pricing. In this regard, the facilitating role of Business Intelligence in the quality of managers' decisions was underlined in particular by the respondents. Business Intelligence supports decisions on promotional activities, allowing for the creation of marketing materials based on collected data, sales forecasting and customer segmentation, as well as customer relationship management. As one of the managers summarised, "Access to historical data shows us what impact the customer has on the company's operations (turnover, costs of manufacturing, new products). We can analyse this, select clients to complete or develop

Tab. 3. Support of I4.0 technologies in companies from analysed industries across the value chain — the summary

Value chain	Project/Design		Inbound Logistics (e.g., supplier management, warehousing)		Manufacturing		Outbound Logistics (warehousing, distribution)		Sales and Marketing	
Industry	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality	Speed	Quality
Food	3D printing, Business Intelligence	3D printing, Big Data	Automation & robotisation	Smart sensors and transmitters, Business Intelligence	3D scanning, IoT/M2M, Business Intelligence	3D scanning, smart sensors IoT/M2M	Automation & robotisation	Automation & robotisation IoT/M2M		Business Intelligence M2M/IoT, Big Data
Furniture	3D printing/ scanning,	3D printing/ scanning,	Automation & robotisation		3D printing, automation & robotisation Business Intelligence, M2M					Business Intelligence, smart apps/virtual solutions
Automotive	3D scanning/printing	Virtual solutions, 3D printing	Big Data	Big Data	Cloud computing, automation & robotisation	Automation & robotisation, IoT		Business Intelligence	Business Intelligence	Business Intelligence

cooperation with, and quickly compare clients in terms of certain indicators and issue them a score on a points scale" (Kappa).

Table 3 summarises the support of I4.0 technologies in companies representing analysed manufacturing industries.

The most similarities, when comparing the three examined industries, could be observed in the Project/Design stage, dominated by 3D printing/scanning. Additionally, in the sales and marketing stage, Business Intelligence support for decision quality was noted in all industries.

Greater differences in support of implemented technologies could be noticed at the Inbound Logistics stage. Automation and robotisation support decision speed in the food and furniture industries, while Big Data provides support for both speed and quality of managerial decisions in the automotive industry.

At the manufacturing stage, differences are evident between the food industry and the other examined industries. In the food industry, 3D scanning and IoT/M2M dominate, providing support for both speed and quality of decisions. On the other hand, in the furniture and automotive industries, robotisation and automation were mainly indicated, offering support for decision-making in the production process.

An interesting observation can be made regarding the Outbound Logistics stage, where technological support is minimal. Only in the food industry respondents identified robotisation and automation as valuable for decision-making, and in the context of improving decision quality, additional support from IoT/M2M was noted. Business Intelligence proved to be helpful in improving decision quality in the automotive industry.

4. Discussion

Managers from the manufacturing industry are mostly aware of the benefits resulting from the application of I4.0 technologies. They also emphasise that such technologies facilitate their decisions. Thanks to I4.0 technologies, managers can make decisions faster, and as they are based on more accurate data, often obtained in real-time, these decisions have higher quality. Thus, this research aligns with previous studies exemplifying the need for detailed, accurate and timely information for fast high-quality decisions (Darwish et al., 2014). This paper showed that obtaining real-time information and the fast analysis of a large amount of data is facilitated by I4.0 technologies, especially Business Intelligence and Big Data analysis. This confirms the findings by Neziraj and Shaqiri (2018) that real-time, up-to-date information supports the decision-making process. In a similar vein, this research showed results similar to those by Janssen et al. (2017), that as data becomes larger, more complex and more inexplicable, the limited mental capacities of people pose difficulties in interpreting the data and information, and this is where advanced Big Data technologies are greatly needed. This complexity and the limited capacity of people is also one of the reasons why in some decisions, the involvement of managers is eliminated, and decisions are automated. Of course, this may raise

questions about the future of managers and human involvement within companies, but as one of the respondents underlined, "This creates an attractive working environment. Access to data is faster, easier and more attractive, so that's a plus. It can be said that our young employees cannot imagine working without these tools" (Gamma). Thus, the authors agree with de Sousa Jabbour (2018), Pozzi et al. (2023) and Ribeiro et al. (2021) that the manager's role will not be changed by Industry 4.0; however, the tools and techniques will be different.

Although the analysis was carried out within particular stages of the value chain, it must be emphasised that the same technologies can simultaneously support decisions within several stages. For instance, Business Intelligence may facilitate managerial decisions at each value chain stage. Similarly, 3D printing and scanning are used within several stages. This application of the same I4.0 technologies simultaneously within several value chain stages may be linked, first, with the specifics of the technology. This is the case of Business Intelligence that, by definition, allows managers to make better decisions based on technology and data analysis (Kašparová, 2022). As a technology-supported process, BI has universal application as it gathers and transforms the fragmented data of companies and markets into information or knowledge about a company's objectives, opportunities and positions (Wieder & Ossimitz, 2015).

Second, the reason for applying the same I4.0 technology may be linked to the specificity of the value chain itself. As Porter and Heppelmann (2014) argued, it is necessary to reconsider the skills and processes used across the entire value chain due to industrial digitisation. In this context, this research results suggest that the project/design stage creates crucial input for manufacturing; thus, 3D printing and scanning technology can facilitate decisions when designing prototypes and creating an offer for customers, and the subsequent support for decisions during production when products are personalised, or there is a need for validation of materials and finished products (Candi & Beltagui, 2019). Financial efficiency must be mentioned as an additional reason for the wider application of the same technology. When investing in more expensive technology aimed at decision support, there is a need to use its full potential.

Although the same technology may be applied across the value chain, technologies that tend to be more specific to a particular stage can still be identified. This is important, as particular stages of the value chain have at least a partly different specificity and, thus, require different decisions affecting the value created and competitive advantage. In the case of Project/Design, 3D printing and scanning facilitate decisions on prototypes and product design. Inbound and Outbound Logistics decisions tend to be supported by Big Data, Business Intelligence, M2M and robotisation and automation. Similarly, automation and robotisation, along with M2M, are helpful when making decisions on production processes (manufacturing) (Cui et al., 2021). Finally, for sales and marketing, Business Intelligence tends to be most helpful. The impact of BI was identified, but Big Data, which serves to strengthen Business Intelligence, can be assumed to be similarly important (Sun et al., 2018). It should also be emphasised that different technologies are often not used separately. Often, at one stage of the value chain, several I4.0 technologies are used to support decisions and, by synergy, achieve the same positive effect. This is particularly the case when Business Intelligence and Big Data analysis are applied together, for instance, with IoT, M2M or robotisation.

The Industry 4.0 technologies indicated in the study belong to the group of mature technologies (i.e., they are more widely implemented) (Kearney, 2020). At the same time, it is difficult to estimate the potential impact that emerging technologies based on advanced AI/machine learning algorithms will have. However, it can be expected that the scope of their influence, especially on decision-making speed, will be significant, sometimes eliminating the need for "physical" manager involvement.

Conclusions

In contrast to earlier studies that have addressed the impact of Industry 4.0 technologies on supporting managerial decision-making, the research presented in this paper focused on individual value chain stages and the support provided by advanced I4.0 technologies for managers' decision-making within these particular stages. Thanks to this approach, it was possible to provide a theoretical contribution by identifying I4.0 technologies that facilitate the quality and speed of the decision-making process at individual value chain stages, which is an important contribution to making managerial decisions and effective value chain management. The most important technologies in this regard include Business Intelligence, 3D printing, robotisation and automation, and M2M.

The research results are also important from the point of view of identifying the sources of competi-

tive advantage of manufacturing companies. The research results indicated that I4.0 technologies generally positively impact the speed and quality of managerial decisions in the manufacturing industry across most value chain stages. For the Design stage, 3D printing and scanning technologies play a crucial role, allowing for faster prototyping and customisation. The speed of decision-making at this stage is positively impacted, and errors can be avoided. The use of Big Data analysis also facilitates the introduction of product innovations. In the case of Inbound Logistics, robotisation and automation in warehouses lead to automatic decision-making and cost-effectiveness. Big Data analysis is useful for quality control of components and raw materials, and Business Intelligence can help eliminate errors in deliveries and product flow. During the Manufacturing stage, robotisation, automation, 3D printing, scanning, Business Intelligence, cloud computing, and M2M integration enable quick decision-making and speed up production. Predictive maintenance through IoT and M2M communication can help managers react faster to emerging changes and prevent major repairs. I4.0 technologies can also support Outbound Logistics through sensors and IoT to optimise distribution. Finally, BI supports decisions on sales forecasting and customer segmentation at the Sales and Marketing stage. To sum up, although the authors expected greater differences between the use of individual technologies at subsequent stages of the value chain and their support for decision-making processes, some similarities could still be noticed.

The specific technologies and their impact vary across different stages of the value chain, emphasising the need for tailored approaches based on the industry's characteristics and requirements. Industry 4.0 technologies can provide more accurate and up-to-date information for analysis and evaluation, enabling managers to make decisions quickly and accurately. However, the scope of decisions made by managers within the value chain depends on whether a stage in the value chain is managed within the company's structures or outsourced. Managers need to be aware of the potential of I4.0 technologies for each value chain stage and adopt them accordingly to improve their decision-making speed and quality. By leveraging I4.0 technologies, managers can optimise their production processes, reduce costs, avoid errors and improve customer satisfaction. At the same time, I4.0 technologies facilitate predictive analytics for forecasting and anticipating future demand, quality issues and potential risks. This can allow organisations to make better decisions and take proactive measures to prevent problems before they occur. However, managers must also be cautious and ensure that their workforce is trained and equipped to handle the changes brought about by these technologies.

This research had certain limitations. The analysis and conclusions are based on a qualitative study and a purposeful selection of a sample of companies characterised by a rather high level of application of I4.0 technologies. Therefore, when compared to the average company, these analysed entities and their managers may be more aware of the benefits resulting from I4.0 technologies. Similarly, it should also be considered that only selected manufacturing industries were studied, while other industries may show different tendencies with regard to technology support for decision-making process across different value chain stages. Finally, the list of technologies is still open due to various industries systematically spending funds on research and development, and, therefore, the list certainly does not exhaust all the available technologies used.

The limitations mentioned above provide perspectives for directions of further research, i.e., the need for extensive quantitative research that will enable diagnosis of the level of application of I4.0 technologies among companies in general and, above all, identify the general perceived impact of these technologies on managerial decisions. Furthermore, while the authors focused on the quality and speed of the decision-making process, it is important to study the consequences of these processes and to identify how they affect companies' financial and market performance.

Acknowledgment

Funding information: The project financed within the Regional Initiative for Excellence programme of the Minister of Education and Science of Poland, years 2019-2023, grant no. 004/RID/2018/19, financing 3,000,000 PLN

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Volume 15 • Issue 3 • 2023

sciendo

ISMSME International Society for Manufacturing, Service and Management Engineering

received: 25 February 2023
accepted: 30 June 2023

pages: 84-100

Managerial approaches, frameworks, and practices for business model application in public services management in the VUCA environment

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ABSTRACT

Significant gaps in public services management were highlighted when service-dominant logic emerged in services science, resulting in fundamental changes in attitudes. The business model application in public services was initiated by offering public service logic. However, this concept requires justification of its interfaces with management approaches, frameworks, and practices. The VUCA (Volatility, Uncertainty, Complexity, and Ambiguity) environment has changed the existing managerial approach in organisational performance and services management. This paper aims to highlight the key aspects and justify the application of services management approaches, frameworks, and practices (Agile practices, customer experience management frameworks, and the design thinking approach) that coincide with the business model approach in public services management (public service logic) in a VUCA environment. In this paper, the Cochrane Guide to Literature Reviews was loosely followed. The focus was on academic publications and such expert sources as webinars for practitioners. Only publications and expert sources in English were included. The Scopus search engine was used for academic sources. Publications covering at least two of the following domains were included: Customer experience, business model, Agile practices, design thinking approach, public services, and VUCA. The expert sources were selected using purposive sampling when communities of practice were identified by authors with expert knowledge, and the main communication channels within each community of practice were sampled. The analysis showed that public services are defined as public goods that the State's government commits to deliver in line with public values by applying a customer-centric approach. Integrating the design thinking approach and Agile practices help create customer-centric solutions for the customer experience management framework as design thinking helps understand what to do, while Scrum (one of Agile practices) gives the autonomy in deciding how to do it. Each analysed managerial method contributes uniquely to improving public services management in a VUCA environment.

KEY WORDS

business model, VUCA environment, Agile practices, design thinking approach, Customer experience management

10.2478/emj-2023-0022

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Introduction

Fundamental changes in attitudes towards public services management have occurred over the past decades (Osborne, 2021), driven by the introduction of service-dominant logic into services science (Vargo, 2004; Lusch, 2008), leading to the public service logic development (Osborne et al., 2013) in the public domain. This concept introduces the business model logic into public services management. The business model defines how an organisation creates, markets, delivers, and captures (customer) value using available resources. Various management

Gaule, E., Jovarauskiene, D., Petrauskiene, R., Pravalinskas, M., & Rauleckas, R. (2023). Managerial approaches, frameworks, and practices for business model application in public services management in the VUCA environment. *Engineering Management in Production and Services, 15*(3), 84-100. doi: 10.2478/emj-2023-0022

approaches, frameworks, and practices (such as Agile practices, design thinking, and customer experience management) are applied for this purpose. Whereas they provide organisational preconditions to co-create customer value, their efforts are often not aligned.

This is also enhanced by the fundamental changes in the context of public services (a VUCA — Volatility, Uncertainty, Complexity, and Ambiguity — environment; Van der Wal, 2017) that have shown how important well-functioning public services systems are when, in practice, they appear to be highly vulnerable. Consequently, public services systems are under even greater pressure to focus on creating better service value for customers and society and ensure resilience to future challenges. The research focused on the problem of how services management approaches, frameworks, and practices (such as Agile practices, customer experience management frameworks, and the design thinking approach) could coincide with the business model approach in public services management (public service logic) in a VUCA environment.

Thus, this paper aims to highlight the key aspects and justify the application of services management approaches, frameworks, and practices (Agile practices, customer experience management frameworks, and the design thinking approach) that coincide with the business model approach in public services management (public service logic) in a VUCA environment. This raises the following tasks for researchers: (1) to identify the specific characteristics of changes in the public services context (a VUCA environment); (2) to detect management approaches, frameworks, and practices that should be applied to the business model approach in public services (public service logic) to respond to the VUCA environment.

The Cochrane Guide to Literature Reviews was loosely followed in the preparations of this paper. The main focus was on two source classes s in English only: academic publications and expert sources (e.g., webinars for practitioners). Only publications covering at least two of the following domains were included: Customer experience, business model, Agile practices, design thinking approach, public services, and VUCA. Scopus search for scholarly publications was chosen because it had the broadest coverage and availability of subscriptions. Eight hundred sixty-eight full-text publications were included for subsequent content analysis. For data extraction, MAXQDA 2022 software was used.

This paper was prepared under the research project "Public services management system to improve the quality and accessibility of services" (project No. 13.1.1-LMT-K-718-05-0019) funded by the European Regional Development Fund under a grant agreement with the Research Council of Lithuania (LMTLT), funded as the European Union's measure in response to the Covid-19 pandemic.

1. Research approach

In this paper, the Cochrane Guide to Literature Reviews was loosely followed (Higgins et al., 2019). Eligibility criteria. As some domains have very active communities of practice and the academic domain

Tab. 1. Last version of keywords and Scopus search string per domain

	Scopus search string	Search hits
Customer experience	TITLE-ABS-KEY (customer journey map OR value proposition canvas OR user experience OR customer experience OR value proposition)	50 736* 52 282**
Business model	TITLE-ABS-KEY (business model OR business model canvas OR service-dominant logic OR public service logic)	39 033* 40 288**
Agile practices	TITLE-ABS-KEY (agile OR scrum OR kanban OR scrumban OR dual track agile OR product discovery OR product delivery)	41 661* 42 660**
Design thinking approach	TITLE-ABS-KEY (design thinking)	5 549* 5 826**
Public services	TITLE-ABS-KEY (public value OR public services OR value creation OR value co-creation OR service delivery OR service co-delivery OR service production OR service co-production OR service design OR service co-design)	95 071* 97 211**
VUCA	TITLE-ABS-KEY (vuca OR (volatility AND uncertainty AND complexity AND ambiguity)) OR ALL ((vuca 2.0) OR (vuca AND antidote) OR (vision AND understanding AND clarity AND agil*))	579* 623**

* Original search on 01/12/2021
** Update 19/04/2022

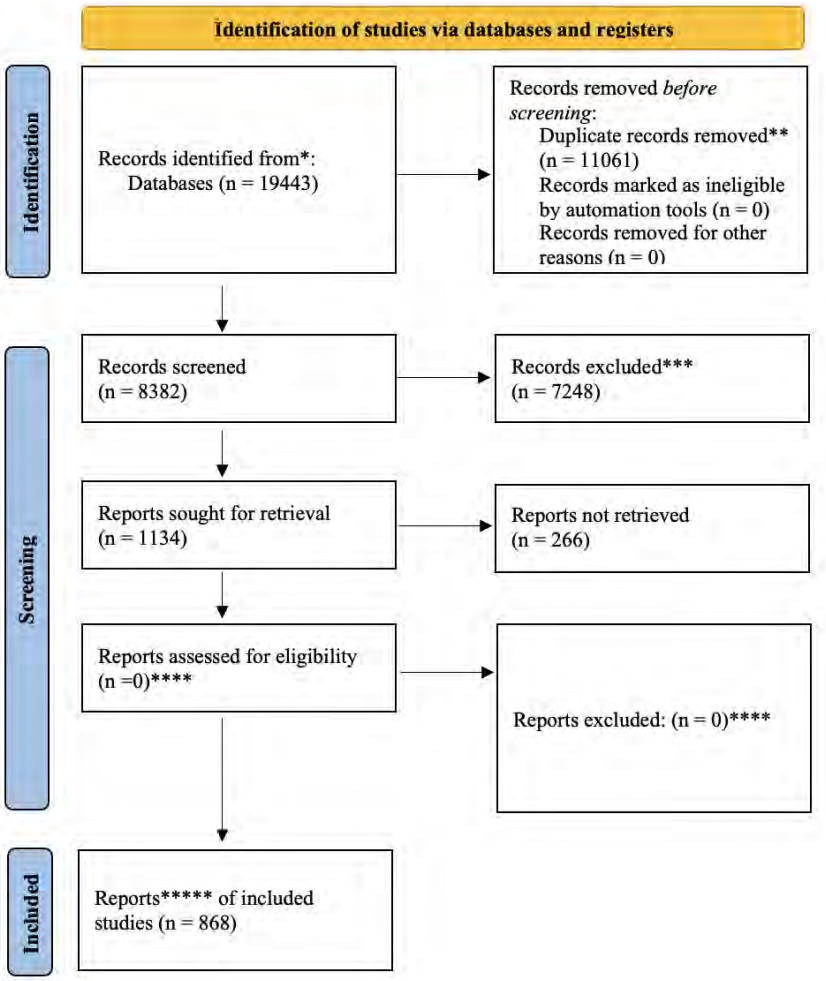

Fig. 1. PRISMA flow diagram

* Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
** Large number of duplicates is due to the search strategy where each domain is represented by intersections of the domain with each of the remaining domains in Table 1.
*** Due to the review strategy and information obtained from the *abstraktr* service, it is not possible to calculate the exact overall number of records excluded by the active learning algorithm. For all six domains, the relevance score threshold of 0.5 was used.
**** Full texts were not assessed for eligibility.
***** Numbers of original studies are not reported here as all research designs were included.

lags behind the real-life developments in businesses (e.g., Agile practices and VUCA), the focus was on two classes of sources: academic publications and such expert sources as webinars for practitioners. Only publications and expert sources in English were included. The Scopus search engine was used for academic sources. No restrictions on publication date and format or type of research (e.g., original qualitative, quantitative, or mixed methods research, reviews, theoretical work etc.) were imposed for academic publications. Publications covering at least two of the following domains were included: customer experience, business model, Agile practices, design thinking approach, public services, and VUCA. The expert sources were selected using purposive sampling when communities of practice were identified by authors with expert knowledge, and the main communication channels within each community of practice were sampled. The most theoretically relevant sources in those channels were reviewed.

Searching for studies. For each domain, a small number of publications conceived by expert knowledge of reviewers were identified. The bibliographic network of their references and references of references were analysed with the NetworkX package in Python (Hagberg et al., 2008). Nodes with the largest degree centrality and betweenness centrality scores were selected, and the most important keywords were extracted following the procedure in the litsearch R package, drawing on Grames et al. (2019). Based on this information, more informed search strings for each domain were finalised (Table 1). Scopus search as the main search engine for scholarly publications was chosen because it had the broadest coverage and availability of subscriptions to the research team.

Selecting studies to include in the review. The selection criteria in the screening phase were set as follows:

- Publications must cover at least one of the reviewed topics.
- Publications must cover any other domain besides the main topic of interest.
- Publications can employ any research method, from theoretically oriented to case descriptions.
- Publications covering culturally specific contexts or cases (e.g., India) are excluded.
- Publications covering software development if managerial methods are specific to the domain or are provided only for context are excluded.

The table above (Table 1) focused on two-way intersections of the domains. Each of the four reviewers covered one or more domains and conducted the initial screening of titles and abstracts using the abstraktr online software (Wallace et al., 2012), which employs an active learning algorithm.

After the screening, 794 full-text publications from Scopus search were downloaded. Besides keyword search, a manual search was used to identify additional candidates (n=104). After de-duplication, 868 full-text publications were included for subsequent content analysis.

PRISMA flow diagram (Page et al., 2021) in Fig. 1 shows the search results and the process of screening and selecting publications.

Collecting data from included studies. MAXQDA 2022 software was used for data extraction. Each reviewer independently used a lexical search utility to find candidates that covered these categories: (i) What is it (descriptions)? (ii) How are the managerial methods combined/integrated? and (iii) Are managerial methods used in the context of public services? If so, how?

2. Literature review and research results

The diversity of public services definitions shows the different conceptualisation perspectives applied in the studies. The definition of public services based on the government functions perspective emphasises public goods creation and provision in meeting the general needs of society/community and ensuring access for all. When the definition emphasises the purpose of services, it identifies public value creation in serving the public interest generally or universally. Public services are often associated with areas of particular importance to the customer (Osborne & Strokosch, 2013) that occur in different areas and are received under diverse circumstances. These services range from meeting basic human and civic needs (e.g., first aid, treatment, medication, housing, determining the legal facts and issuing relevant documents) to improving the quality of life (e.g., monitoring health, informing, educating, empowering, and mobilising community partnerships). Therefore, the individual perspective, including value creation for the customer, is also a significant aspect of public service delivery (Osborne, 2021, p. 43). According to McBride et al. (2019), public value and its creation is becoming more complex and requires more detailed research for several reasons: (1) public value is not static, (2) public value is what is created at the societal level, and (3) public value is the output or result of some service or activity. Public services are provided according to both the common needs of society/community and individual needs, leading to customer and public value creation. Summarised in this paper, public services are defined as public goods that the government commits to deliver in line with public values by applying a customer-centric approach.

2.1. Business model application to public services

Although the concept of business models and related business model innovation originated in business organisations (Al-Debei & Avison, 2010), it does not apply to every organisation as, regardless of its sector, every business creates, delivers, and captures value (Kaplan, 2012; Timmers, 1998; Zott et al., 2011). This concept is also relevant to organisations that provide public services (Magretta, 2002). According to Ranerup et al. (2016), various research-

ers of business models emphasise different aspects: the role of value creation logic (Zott & Amit, 2008; Zott et al., 2011), business processes (Osterwalder, Pigneur & Tucci, 2005), resource base and its longitudinal evolution (Hedman & Kalling, 2003). However, the business model (BM) is much more than only the descriptive narrative required to lead practical action (Magretta, 2002). In general, the BM concept includes the following interrelated components: (1) customers, (2) competitors, (3) services, (4) activity and organisation, (5) resources, and (6) supply of factors and production costs. Thus, it covers overall strategy aspects and economic and revenue models. The main purpose of the term is to help organisations manage services, and researchers carry out case studies that identify weaknesses of existing or inappropriate BMs (Timmers, 1998; Afuah & Tucci, 2001; Hedman & Kalling, 2003). All components can be treated as cross-sectional and examined at different points (Baden-Fuller & Morgan, 2010). Considering the importance of the changing environment, BMs must be dynamic and include a longitudinal process (Hedman & Kalling, 2003). Thus, the BM application is relevant to organisations operating in the VUCA environment.

One of the most prominent analytical systems that have received considerable attention due to its practical application is Osterwalder's BM Canvas (Aljena, 2014), which describes the rationale for how an organisation creates, markets, delivers, and captures value (Osterwalder, Pigneur & Tucci, 2005). The BM Canvas is used to describe, analyse, or create a new BM and has been used primarily in business organisations to better understand their processes and to develop new strategies. According to this system, a BM is interpreted as a canvas including nine elements, which are arranged into four groups: customers, offer, infrastructure, and financial viability (Díaz-Díaz et al., 2017). BM Canvas includes activities, resources/competencies, costs, revenue streams, partners/networks, communication channels, and relationships with recipients/users, and depends on specific BM (Wirtz et al., 2016).

The emergence of the business model is often associated with a competitive business environment; however, organisations offering public goods and services also rely, to some extent, on key BM components. From the general services perspective, in public organisations, BM components' relevance is mostly related to the issues and dynamics of information systems (Al-Debei & Avison, 2010; Panagiotopoulos et al., 2012; Ranerup et al., 2016). However, public governance researchers, by introducing public service logic, emphasised a customer-centric approach, as the customers of the services perceive the value and focus on total shared value creation between services, organisations, and customers (Osborne et al., 2014; Osborne, 2021; Alwash et al., 2021). The application of public service logic is intricately linked to the sustainability of public services systems, as the knowledge application regarding customer experience offers favourable opportunities for public services development (Alford, 2016; Osborne et al., 2015).

2.2. Public services in the VUCA environment

The complexity and ambiguity in the public organisation context and the need to operate in unpredictable demand conditions lead to an innovative approach to a business model based on visionary strategies (Karpen et al., 2012; Shepherd et al., 2021; Kafel & Zięb icki, 2021). Addressing such a public organisation context requires strategies that depend on concepts and tools and allow for an innovative approach to the application of BMs (Bryson, Berry & Yang, 2010; Brorström, 2020). In this context, the BM approach is particularly valuable because public organisations operate in a VUCA environment (Wirtz et al., 2021).

Considering the main business model components, research in public organisations is related to the value creation and value capture dimensions (Edralin et al., 2018). It further clarifies value dimensions using the BM Canvas. Thus, for public services organisations (non-profit organisations), the non-profit Canvas called Mission Model Canvas was developed by Newell, Osterwalder and Blank in 2016. The main difference from the original concept is that this canvas is adapted to public services in which customers are treated as beneficiaries, and a value proposition is offered. The Mission Model Canvas targets organisations whose mission implementation has secured funding (based on public funding) that is not typical for business organisations looking for the best BM idea. BM Canvas, developed by business representatives, is recognised and can be applied to public organisations; however, its links to public service logic and its application in public organisations using Mission Model Canvas are limited.

Public services are provided in a dynamic and changing environment, and their operating principles must respond to changing needs of society and social perceptions (Lenaerts, 2012). Cognition is required

for recognising essential changes in the context of public services, which are described in various terms. One term framing the context in services science and practice is the VUCA environment. This concept is beneficial because it helps leaders understand the environment in which they operate (Johansen & Euchner, 2013). The VUCA acronym was coined by the U.S. Army War College and was first placed into the curriculum AU1988 in 1987 (U.S. Army Heritage & Education Center, 2021). Volatility is the intensity of fluctuations over time (Gläser, 2021) and is liable to change rapidly and unpredictably when events of unexpected occurrence and durations disrupt systems and norms (Van Der Wal, 2017). Thus, in a systemically volatile environment, change is constant. Uncertainty is the unpredictability of numerous events (Gläser, 2021) with unclear short- and medium-term consequences (Van Der Wal, 2017) when outcomes of non-linear interactions of a number of elements cannot be known beforehand. Complexity is being affected by several influencing factors and their interdependence or interaction (Gläser, 2021; Çiçeklioğlu, 2020) when events and issues feature and their interrelations are hard to understand (Van Der Wal, 2017). Ambiguity occurs due to the lack of models that explain observed phenomena since simple linear cause-and-effect descriptions provide more than one interpretation of a situation or information (Gläser, 2021; Nishimoto, 2021). Consequently, reality could be hazy, and there could be a high potential for misreading events and issues, as they are marked by contested, hidden, and inconsistent information (Van Der Wal, 2017). Although complex and complicated terms are often used incorrectly as equivalents, the definitions should be distinguished by the fact that a complicated system can be simplified without being destroyed, in contrast to a complex system that cannot (Gläser, 2021).

VUCA calls for a leadership response or behavioural leadership model called VUCA Prime (Johansen, 2007), VUCA 2.0 (George, 2017), or VUCA 2.0 Antidote (Faecks, 2021). In contrast to VUCA 2.0 (George, 2017), which has a traditional organisation focus on strategic leadership, VUCA 2.0 Antidote (Faecks, 2021) goes beyond empowering the leadership to be closer to the employees inside the organisation and towards deeper employee communication and engagement as well as close customer experience and competition revival through:

- Vision — the ability to see through the chaos of the storm and be the guiding star of the organisation's mission, values, and strategy (George, 2017). Additionally, the need to be transparent emphasises that the employees be devoted to the mission and hold a common understanding of values and strategy to secure relevant, informed decisions (Faecks, 2021; Çiçeklioğlu, 2020).
- Understanding — the need for a deep perception of an organisation's capabilities and strategies to maximise strengths and minimise weaknesses (George, 2017) or have a far-reaching understanding of structures and processes to quickly and effectively apply skills that exist within the organisation; additionally, possess an in-depth understanding of customers and competitors and changes through transparent communication and networking (Faecks, 2021).
- Courage — the need to make audacious decisions and take new challenges and risks (George, 2017), or clarity (in addition to courage in VUCA 2.0) — the ability to focus and formulate the organisation's management through effective countermeasures implementation, resulting in more structured processes, more efficient communication channels, and quick and transparent decisions for employees (Faecks, 2021).
- Adaptability — the need for flexible tactics without altering the strategic course (George, 2017; Çiçeklioğlu, 2020) or agility (in addition to adaptability of VUCA 2.0) — organisations need to establish flexible processes and cross-functional cooperation (Faecks, 2021).

Current VUCA challenges require addressing its aspects by new perceptions, e.g., that give up traditional conceptions of strategy and leadership (Systems Innovation, 2019) and transform strategic leadership dramatically from the traditional heroic leadership of centrally controlled organisations to various modern leadership styles firmly rooted in empathetic leadership (Jordaan, 2019). Empathetic leadership is a style of leadership that focuses on identifying with others and understanding their point of view (Robbin, 2022a). Empathy is an essential part of various leadership styles aimed at building relations via increased trust, stronger teams, better decision-making, increasing influence, and more promotions (Robbin, 2022b). Although communication, delegation, and the ability to motivate others are likely leadership skills, empathy — a key quality of a truly effective leader — has often been overlooked and underestimated (Nodding, 2021) until recently (Robbin, 2022a).

Due to volatility, the strategy needs to evolve from resisting it to working with it through agility

and enabling adaptive capacity (Systems Innovation 2019). In a VUCA world, the organisational strategy must be clear regarding where to go but flexible in how to get there (Johansen & Euchner, 2013). Thus, empathetic leadership of volatility through vision requires steering via an often repeated simple and authentic vision (Agile Leadership, 2020). Furthermore, the team should be engaged in the vision development, in addition to its repetition, where an emphatic leader uses active listening, facilitating, and moderation skills.

Second, due to uncertainty, the strategy shifts from defining one environment in the future that is most probable and creating a single optimal strategy for this to developing organisations that can operate under multiple outcomes through increased diversity (Systems Innovation, 2019). Thus, the challenge of leadership is to develop clarity but moderate certainty (Johansen & Euchner, 2013). Empathetic leadership of uncertainty through understanding requires comprehending the current worries of the team as well as being fully transparent in the organisational reality in the present world (Agile Leadership, 2020), thereby creating trust.

Third, due to complexity, strategic leaders must focus on creating the context that enables the emergence of the desired outcomes instead of delivering them (Systems Innovation 2019). Clarity counters confusion and enables action; however, there should be clarity of intentions and direction, not just response; a high degree of flexibility in means; and the ability to turn a threat into an opportunity (Johansen & Euchner, 2013). Emphatic leadership through complexity with clarity and communication requires an empathetic leader to be clear about the goals set, call the team to action, and be consistent in leadership, e.g., asking the team to change habits to adapt to a new reality (Agile Leadership, 2020).

Fourth, due to ambiguity, strategic leaders need systems thinking to see interconnections and gain different perspectives (Systems Innovation, 2019). Emphatic leadership, through ambiguity with agility or adaptability, implies various roles based on relevant competencies (Agile Leadership, 2020), e.g., roles of Expert, Achiever, Catalyst, Co-Creator, Synergist (Joiner & Josephs, 2008), Moderator, and Facilitator.

Summing up, the VUCA world strategically challenges organisations and individuals to seek success. It calls for immersive learning experiences and strategic-foresight development using multiple methods synergistically to create and explore scenarios (Heger & Rohrbeck, 2012; Johansen & Euchner, 2013). Meanwhile, empathetic leadership enables the fastest response and shortest resolution times to respond to the changes directly with autonomous teams or even empowered individuals to drive value co-creation with the customer.

2.3. Agile values and practices in public services

In February 2001, a group of software development practitioners called "The Agile Alliance" developed a brief document built on four values and twelve principles for agile software development (Bedle et al., 2001a; Beck et al., 2001b; Highsmith, 2001). Authors of the Agile Manifesto chose Agile because the term represents adaptiveness and response to change, which was important for their approach (Agile Alliance, 2022).

The Agile Manifesto stated four core values of Agile software development. First, working software over comprehensive documentation defines the Agile philosophy as condensing the functional requirements into user stories and starting development in iterations significantly earlier, in contrast to the waterfall process that uses a long analysis stage before development or real creation of value starts. It means creating enough documentation to support working deliverables but not more than needed to support and develop it further (Wrike, 2022a; Wrike, 2022b). Second, responding to change over following a plan means: the Agile team should be willing and able to adapt to changing customer expectations and requests rather than sticking to a fixed scope. Agile teams work in short, iterative cycles, meaning they can react quickly and implement changes continuously (Wrike, 2022a; Wrike, 2022b).

Third, customer collaboration over contract negotiation means that the Agile team outlines product requirements with the customer directly as opposed to through contract negotiations (Wrike, 2022a; Wrike, 2022b). Consequently, the Agile team gets customer feedback earlier during the expectations phase, not the acceptance phase. Fourth, individual interactions and interactions over processes and tools mean that processes and tools should be flexible enough to adapt to the needs, skills, and priorities of team members and stakeholders (Wrike 2022a). According to Agile philosophy, people are more important to creating value than processes and tools.

Agile philosophy focuses on teamwork, where each participant contributes to the desired outcome

during the process (Hurochkina & Zvonar, 2020). Considering that Agile values unite people for success and create a robust background to resolve tough dilemmas due to ambiguity, Agile philosophy remains practical and promising in describing the emerging world. Thus, Agile values address all aspects of the VUCA operating environment and perceptions of how to deal with VUCA challenges.

Different management approaches were developed to embody Agile values. Scrum is the most popular Agile approach used by software development teams (66 % of the teams follow it most closely, with an additional 15 % who follow ScrumBan at 9 % and Scrum/XP at 6 %) (5th Annual State of Agile Report, 2021). Scrum is a disciplined and lightweight framework that helps organisations generate value for complex problems through innovative and adaptive solutions based on continuous improvement (Mathew, 2019; Schwaber & Sutherland, 2020). It is based on an iterative and incremental process of inspection and adoption when complex tasks are implemented step-by-step, leading to unpredictable and unrepeatable outputs. Scrum has predefined roles (product owner, product developer, and Scrum master) with presumed leadership styles (Visionary, Democratic, Affiliative, and Empathetic) that address VUCA world challenges.

Dual-track Agile is a methodology that combines product discovery (in other words, validation of products, services, or features before implementation) and product delivery (in other words, the technical implementation and deployment of the identified outputs of discovery) (Cagan, 2012; 2018; Trieflinger et al., 2021). Discovery track outputs become the inputs of the delivery track. The simultaneous execution of product discovery and delivery through fast release cycles allows the team to adapt the solution to the customer's needs more quickly (Trieflinger et al., 2021). Thus, Dual-track Agile helps organisations focus on the right kind of innovations for the markets and deliver products for which customers will pay. It leads to better results with fewer resources and efforts, i.e., better products, less time spent, and lower development costs.

These Agile approaches are generic for application in various domains (Wastell, 2011) but difficult to implement in public management as they require the immediate involvement of all relevant professionals, i.e., building cross-functional teams. However, these flexible frameworks are more progressive compared to others (Hurochkina & Zvonar, 2020) as they are a model of management for non-routine processes of teamwork that uses the sociotechnical approach in action by self-organising, learning, and minimal structures (Wastell, 2011).

2.4. Customer experience management in public services

The definition of customer experience (or user experience) has been discussed and is well established. It differs from other similar concepts (e.g., service experience) in its clear focus on experience, i.e., the customer (Bueno et al., 2019). This concept of customer experience evolved from classical usability, and its focus is distinctive in creating a positive customer experience. As customer experience emerges from the interaction between a customer and an organisation (its brands, services and/or products, employees) (Lemon & Verhoef, 2016), it represents several aspects of the concept corresponding to the position of the participant in this interaction (Johnston & Kong, 2011). From a customer's (as an individual) perspective, customer experience is defined as a multidimensional construct based on a set of cognitive, emotional, behavioural, sensory, and social responses of the customer (Lemon & Verhoef, 2016; Teixeira et al., 2012). Thus, it has a subjective and internal nature (Meyer & Schwager, 2007) arising from personal interpretation of the benefits and value of the services, experience in the services process (Johnston & Kong, 2011), and inclusion in it. From an organisational perspective, customer experience is seen to be a psychological construct of customer sensation or knowledge acquisition (Verhoef et al., 2009) based on the overall organisation's offer experienced during the customer's journey at each touchpoint (Homburg et al., 2015). Customer experience is dynamic because customer sensation or knowledge is shaped during, before, and after (Bueno et al. 2019) direct or indirect contact (Meyer & Schwager, 2007) and influenced by the VUCA environment.

Service is a customer-organisation interaction-based process; thus, services are co-produced through multiple interactions with the customer. Instead of offering an experience as such, organisations develop the preconditions for customers to gain the desired experience. In such a framework, customer experience consists of three component types: (1) touchpoints (customer and organisation interaction points), (2) context (internal and/or external customer resources available in the situation), and (3)

qualities (attributes reflecting the nature of customer responses and reactions to interactions) (De Keyser et al., 2020).

A customer experience is self-perceived by the customer as it is based on a subjective interpretation of a series of interactions developed by the service provider. Thus, the customer experience arises from factors that the organisation can directly control (the process of the service delivery or interaction with an employee at the touchpoint) and cannot directly control (an internal perception or interaction with other customers). Customer experience management (CEM) is defined as an organisation's strategy to manage all customer interactions, including individual touchpoints, the overall customer journey, and the physical and social environment (Zomerdijk & Voss, 2010).

At the core of customer experience is the value co-creation between the customer and the provider, as services become meaningful only concerning a customer and not otherwise. Therefore, the organisation does not create value for the customer but presents a value proposition as a design for the customer experience. A value proposition does not have control over the customer's value creation but sets the stage for customer experiences, i.e., empowers the customer for action to create value through their experience. Service design is focused on integrating service features with the customer's psychological aspects of functional and emotional value on perceived accessibility and quality of services. The level of customer involvement in developing a service offering may vary as service providers can consciously involve customers in the determination, development, and refinement of the service experience or foresee and meet customer needs and expectations through an active experience (Beltagui et al., 2016). Therefore, diverse services mapping tools (such as customer journey maps) are used to shift the focus to the customer experience, emphasising the emotional and functional aspects of the customer's journey rather than the defined touchpoints from the services provider's perspective.

2.5. Design thinking approach in public services

As a collaborative problem-solving tool, design thinking has received increasing attention from researchers and practitioners trying to find ways to innovate both in business and public organisations. It can help solve different challenges faced by organisations. It starts with human needs and uses suitable technologies to create entrepreneurial value through customer value (Brenner et al., 2016).

The design thinking approach (DTA) is design oriented, where the concept of design has usually been described as a process or a creation (Adikari, McDonald & Campbell, 2013). In design, the ability to emotionally understand customers is recognised as crucial and leads to empathy, which then inspires and helps create designs that meet customer needs and expectations. DTA uses creative tools, such as persona, empathy maps, and prototyping, to address complex managerial activities and ensure empathy with customers (Brown, 2010; Carlgren et al., 2014).

Initially, design as a process was applied to business organisations to innovate individual projects, internal processes, and entire BMs (Brown, 2009). The word "thinking" came together with "design", trying to explain the function of designers. Design thinking is usually perceived in different ways, i.e., as a mindset, toolset, and process (Stickdorn et al., 2018; Brenner et al., 2016; Liedka & Salzman, 2016; etc.). As a mindset, design thinking is usually based on the following main principles (Brenner et al. 2016; Brown 2008; etc.): make innovations by and for humans; combine divergent and convergent thinking; fail often and early as this facilitates learning; build prototypes that can be experienced; test early with customers; work in the iterative cycles; and design in a flexible space. As a process, design thinking is based on the mindset that attempts to find innovative solutions through iterative cycles of research and development. DTA provides a robust, creative, and innovative process (Nedeltcheva & Shoikova, 2017). As a toolset, design thinking involves applying various methods and techniques from different disciplines (e.g., design and engineering). As a cross-disciplinary language, DTA helps designers understand customer needs and behaviour and develop new problem-solving skills (Muratovski, 2012). A cross-disciplinary language is needed that combines multidisciplinary, interdisciplinary, and transdisciplinary ways of working (Muratovski, 2017). If design thinking is sustainably applied in an organisation as a management approach, it can be exploited as a management approach to both the incremental innovation of existing value propositions and radical innovation for completely new services or products (Stickdorn et al., 2018).

Different variations in the stages proposed by the existing design thinking models or frameworks can be found in the scientific literature (Tschimmel, 2012;

Plattner, 2015; Stickdorn et al., 2018; Duggan, Roberts & Dahl, 2017; etc.): IDEO model, Institute of Design at Stanford (DSchool) model, 4D or Double Diamond model of the British Council, the design thinking model of the Hasso-Plattner-Institute (HPI) academy, and the human-centred design (HCD) model, among others.

According to Brown and Wyatt (2010), DTA transcends the borders of public non-profit and profit sectors, and close collaboration with customers allows high-impact solutions to come bottom-up rather than top-down. Design thinking, with a strong focus on the real customer experience, seems particularly valuable in addressing the complex social challenges faced by governments and public organisations (Liedka & Salzman, 2016, p. 10). Fundamental elements of design thinking in public organisations include customer-centricity, i.e., design solutions that must become part of people's living experience (Krippendorff, 2006); empathy and deep research of customers; and multidisciplinary teams that are effective in mitigating several cognitive biases during the idea generation process (Trischler et al., 2019). Accordingly, these teams also use unique formats, e.g., Scrum methodology, which includes development times divided into short so-called design sprints. The methodology and the tools applied during the sprint cycles need to be purpose-built for the underlying context to successfully consider related barriers and opportunities (Trischler et al., 2019).

Summing up, design thinking is a human-centred, collaborative, cross-disciplinary, iterative approach applied to research, prototyping, and a set of activities and visualisation tools to meet the needs of customers, create a positive experience for them, and provide high-quality public services.

3. Discussion of the results

The following discussion concerns compliance aspects of the customer experience management frameworks, Agile practices, and the design thinking approach with the business model (public service logic) and the compatibility of these concepts.

Business model and customer experience management. Customer experience results from the co-creation process of customers interacting with several service elements (Vargo & Lusch, 2004; Teixeira et al., 2012). Thus, the shift from service to customer experience requires CEM that integrates the customer domain, service domain, and BM and relevant concepts to meet customer experience requirements (Laghari et al., 2010). CEM can be used as a modelling tool in the early stages of service design (Teixeira et al., 2012, p. 363) to manage complex realities as different elements of services lead to various, more compelling contexts (Zomerdijk & Voss, 2010) and ensure a creative transition to service design decisions (Patricio et al., 2008) arising from a previously accumulated knowledge base.

Business model and Agile practices. Agility expresses new ways of a BM's development and running of services to meet challenges (Xu & Koivumäki, 2019) because different customers have different requirements, and these requirements alter over time. A business model leads to agility as not only the business model design comes from the continuous iteration during the different ongoing stages of new service design but also the continuous development and/or testing of the business model in different environments. Thus, the business model embodies the ability to adapt and respond to unforeseen change and uncertainty, i.e., agility. Furthermore, business modelling helps activate teamwork, prioritise, and plan actions.

Business model and design thinking approach. According to the business model, an organisation is treated as an integrated system that encompasses the services environment and development process. The public services design process is a multistage process of design thinking application. Depending on the specific situation, different tools can be used at various stages, e.g., the content identified in the discovery and definition stage has a major impact on customer experience value (Lee et al., 2021, p. 199).

Design thinking approach and Agile practices. If Agile is a mindset that addresses specific issues related to the ongoing delivery of services, the goal of design thinking is to identify challenges that need to be addressed first (The Service Design Playbook, 2017). The design thinking process is designed to define the customer experience and behaviour and help frame challenges and generate innovative service improvement ideas (Nedeltcheva & Shoikova, 2017). Design thinking helps understand what to do, and Agile practice gives the autonomy to decide how to do it (Nedeltcheva & Shoikova, 2017). Although Agile practices (e.g., Scrum) and design thinking seem quite different, they contain some important similar concepts, such that both can be integrated. They are both iterative processes; they require recognising early successes and failures through continuous evaluation and adaptation, and both rely on self-organis-

Tab. 2. Compliance of selected managerial concepts with public service logic

Criteria of public service logic in the VUCA environment	Agile values and practices	CEM framework	DTA
Customer- (human) centric approach/ empathy (Osborne, 2021; Teixeira et al., 2012)	Customer satisfaction is a priority; accomplished by iterative deliveries of small working sets of features to the customer (Jurca et al., 2014), incorporating customer feedback as part of the requirement process and including end-user feedback during all development phases (Nedeltcheva & Shoikova, 2017)	Customer orientation is a point of departure (Lemon & Verhoef, 2016; Johnston & Kong, 2011). Is based on empathic research to define customers' needs and find ways to innovate (Zomerdijk & Voss, 2010). Is used to design, test, replicate, and develop services (De Keyser et al., 2020)	Putting real people's needs at the centre and engaging them in shaping solutions (Adikar, McDonald & Campbell, 2013; Liedka & Salzman, 2016; Allio, 2014; etc.). based on empathy as the capacity to understand and imaginatively step into another person's shoes (Allio, 2014; Liedka & Salzman, 2016)
Value (co-)creation (Osborne, 2021; Kaplan, 2012; Karpen et al., 2012)	The process of value creation emphasises people, not processes and tools, empowering the employees and customers (Mathew, 2019; Schwaber & Sutherland, 2020)	Changing management tactics from service quality to customer experience quality (Bueno et al., 2019). Tailoring the service to the customer to get a meaningful impact on how consumers perceive the level of value received (Homburg et al., 2015)	This is the basis for providing the supporting resources to enable customers to integrate and operate (Trischler & Charles, 2019). The involvement of customers, employees, and other stakeholders in the design process has been seen as an important driver for service design (Mager & Sung, 2011)
Leadership–followership relations (Johansen & Euchner, 2013; Joiner & Josephs, 2008; Nodding, 2021)	Transforms strategic leadership from traditional to various modern styles firmly rooted in empathetic leadership (Johansen, 2007; Jordaan, 2019; Faecks, 2021; George, 2017)	As customer experience is largely unmanageable in the traditional command and control sense, and thus total engagement across the organisation is required (Homburg et al., 2015), including ownership, responsibility, and leadership in customer focus	The team composition is an essential element in ensuring the necessary solutions' diversity (Liedka & Salzman, 2016). It is linked with stewardship, defined as the core ability of change agents to successfully achieve the desired outcomes (Allio, 2014)
Learning culture (Johansen & Euchner, 2013; Mergel et al., 2021)	Agile practices (e.g., Scrum and Dual Track Agile) are advanced in unconventional teamwork processes (Hurochkina & Zvonar, 2020) by promoting self-organisation and continuous learning (Wastell, 2011)	By creating positive memories of the experience, an organisation may change the customer's perception and influence their future behaviour (Johnston & Kong, 2011). Satisfaction does not measure the customer experience; thus, the use of both operational and experience data to measure, track, and improve the customer experience is important (Lemon & Verhoef, 2016). Systemic improvements	When the environment is uncertain, stakeholders are not coordinated, and quick learning together becomes necessary (Liedka & Salzman, 2016). To ensure collaborative creativity, knowledge is created through social interaction

Criteria of public service logic in the VUCA environment	Agile values and practices	CEM framework	DTA
Scenario building/development (Heger & Rohrbeck, 2012)	Agile practices use user stories to enable scenario building (Johansen & Euchner, 2013; Wrike, 2022a; Wrike, 2022b)	Based on the perception of the customer experience, the provision of services is analysed (Teixeira et al., 2012). The organisation uses a guiding zone of tolerance of customer experience as the specific customer experience is unmanageable (Bueno et al., 2019)	Designing means thinking about what problem customers encounter in a specific time, place and task flow and building up the scenario in the process of solving the problem by giving the best solution (Wang et al., 2021)
Collaboration/involvement/engagement of customers (Debei & Avison, 2010; Panagiotopoulos et al., 2012; Ranerup et al., 2016)	An Agile team outlines product requirements based on customer collaboration over contract negotiation (Wrike, 2022a; Wrike, 2022b)	Customer co-creation is the process of collaborating with customers in a problem-solving or ideation process to get fresh ideas, solutions, or customer input (Beltagui et al., 2016; De Keyser et al., 2020). The highest engagement can only be achieved if the customer comes already having a good experience (Lemon & Verhoef, 2016)	An open culture of collaboration is essential when facing a complex challenge. Collaboration refers to interactive and collective thinking, teamwork, and networked design collaboration (Liedka & Salzman, 2016; Allio, 2014; Lee, Ostwald & Gu, 2020; etc.)

ing and interdisciplinary teams. Furthermore, they value reflective practice and the concepts of testing and improving through iteration (Dobrigkeit, Wilson & Nicolai, 2018). Nevertheless, neither design thinking nor Agile practices provide support for tracking growth and scaling a service after its delivery.

Design thinking approach and customer experience management. CEM seeks to facilitate an understanding of the customer experience and provide valuable insights to support the service design process (Teixeira et al., 2012, p. 11). Design thinking can be used to create a positive customer experience, especially when the challenge addressed is not clearly defined. Thus, it is important to incorporate design thinking into the CEM early enough in the process.

Customer experience management and Agile practices. Agile practices may be applied in the redesign and digitalisation of public services, especially in the initial requirement analysis based on customer experience modelling (Mergel et al., 2021). At the heart of the Agile application in service design development is the recurring interaction between the design of customer experience and service features, as well as technology selection. Accordingly, Agile methods enable organisations to design services that are valued by the customers.

The integration of the design thinking approach and Agile practices help create customer-centric solutions for the customer experience management framework as design thinking helps understand what to do (identifying problems and challenges and generating ideas of innovative solutions), while Scrum gives the autonomy in deciding how to do it (within a creativity enabling environment).

Conclusions

In this paper, public services are defined as the services that the State commits to aiming to (1) create public value and (2) ensure that the public interest is guaranteed for achieving the objectives of solidarity and equality in society. A holistic approach to public services emphasises them as a process; however, the modern approach highlights the importance of value creation for the customer (society) rather than the process. The concept of public services emphasises the provision of welfare achieved by adding customer value without reducing social value. In this context, the junction between public value and customer value becomes more pronounced. This is what public service logic means.

VUCA clearly reflects the characteristics of the emerging world through the aspects of Volatility, Uncertainty, Complexity, and Ambiguity, as well as by responses to performing in such an environment

of Vision, Understanding, Courage, Clarity, Adaptability, and Agility. The VUCA environment strategically challenges organisations and individuals to achieve success. Meanwhile, empathetic leadership enables the fastest response and shortest resolution times to respond to the change directly with autonomous teams or empowered individuals to drive value co-creation with customers in the public or business domain.

The business model foundation is an approach to organisational performance and its relationship with the customer that demonstrates the integration of customer value creation (as an organisation's overall orientation) and internal processes. Public organisations lack customer-centricity (e.g., over time and between segments) and managerial flexibility (due to funding and regulatory constraints). Public service logic, in contrast to service-dominant logic, is specific due to differences in the specificities of the services, e.g., the value to the customer and the society gained from limited resources and framed by formal requirements of legitimacy.

The value to the customer lies not in what the organisation does (in other words, not an inward-looking approach) but in how the customer creates value through their experience. The organisation creates the preconditions for creating customer value. Therefore, customer involvement in the design of the services is valuable regarding the final result. Customer experience management is based on a multidisciplinary approach that emerges due to the diverse information from many sources about customer experiences.

Accordingly, it reveals the holistic nature of the customer experience. Customer experience management is a purposeful, organised, and structured (cheaper and faster) move of an organisation towards value creation for the customer. This increases the efficiency (cheap and fast) and effectiveness (responds to need) of services, forms satisfaction and earns trust.

Agile values address all VUCA world operating environment aspects and perceptions on how to deal with VUCA challenges. Considering that values unite people for success and create a robust background to take tough decisions, such as during dilemmas, Agile practices sound promising, performing in the VUCA environment. Nevertheless, they were historically based on software development, not business management.

With its strong focus on the research of real customer experiences, the design thinking approach is particularly valuable in addressing the complex societal challenges public organisations are facing. The design thinking approach provides a new approach to public services, helps listen to customer experiences, uses visualisations, prototypes, and tests them with real customers, and follows learning by doing.

Each managerial method analyses and contributes in its unique way to improving public services management in a VUCA environment. Customer experience management provides a common vision that includes a values-based strategy and leads to a mission. A good understanding of the general environment and specific situations enables clarity in management decision-making. While customer experience management leads to understanding an organisation's capabilities and strategies, Agile practices enable an understanding of organisational structures and service development processes. Agile practices provide tactical flexibility as adaptability towards changing environments without changing strategic course. The design thinking approach ensures an in-depth understanding of customers.

As the organisation's performance results from synergistic interactions of many structures and processes, it requires a unified approach by integrating various managerial methods, e.g., both Agile practices and design thinking approach include principles, methods, and toolkits. If cleverly applied together, both can help teams generate solutions that bring new value to customers, thereby improving the customer experience management framework. Design thinking approach and Agile together can create a customer-centric environment focused on fast, frequent iterations for optimal results. Although the design thinking approach and Scrum (as an Agile practice) seem different initially, the analysis reveals several similarities (e.g., both recognise early successes and failures, iterative processes, and self-organising and interdisciplinary teams). Therefore, the design thinking approach and Scrum can supplement each other when the design thinking approach helps generate a customer-centric solution, and Scrum helps realise that solution.

Future research and challenges for practitioners:

- Although the design thinking approach and Agile practices are creative and innovative, they lack a solid theoretical foundation as managerial tools in services science;
- The general concepts developed in public governance science (such as public service logic) do not lead to practical application tools or methods. In this way, scientific knowledge does not signifi-

cantly change management practices and does not provide an opportunity to develop public management practices;
- In the case of public services, there is a need for adaptation and redesign of general management approaches, frameworks, and practices according to the characteristics of public services. In one case, these may be systemic aspects that apply to many concepts, while in others, they are concept-level issues;
- Integration of different management frameworks and practices into a common unified whole at an organisational level is challenging too. As the need for customers to be at the heart of the business process in organisations arises, agile internal processes are required. Thus, methodological issues for the integration of managerial concepts arise.

As regards the research limitations, the project is still being implemented, so the article only provides theoretical insights into managerial approaches, frameworks and practices of BM application in public services. In the future, the benefits of using the referral method in organisations that administer and provide public services need to be investigated. It will be the next step while implementing this project.

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sciendo

received: 10 March 2023
accepted: 1 July 2023

pages: 101-114

Methodology of an interpretive structural map construction for social commerce success

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ABSTRACT

The factors influencing consumer purchase decisions in electronic commerce platforms and the interrelationships of each element are prevalent in the domain literature. However, a comprehensive analysis of the complex interrelationships among the success factors remains unexplored, especially in a social commerce context. To address the gap, this work evaluates the relationship structure and determines the critical factors using interpretive structural modelling (ISM). On the other hand, the Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (MICMAC) is introduced to analyse the interaction of the factors and recognise the most relevant among them. In demonstrating the ISM-MICMAC analysis, this work performed a case study evaluating 13 factors of social commerce success for food products derived from a previous study. The findings of this work suggest that timeliness, data privacy policy, and Internet connectivity drive most other factors. Thus, focusing the resources on augmenting these factors consequently improves other factors. These findings suggest that sellers must streamline their overall service chain to maintain timeliness in their transactions, safeguard consumers' data privacy, and uphold consumer communication efficiency to maximise Internet connectivity. These insights provide useful information to help decision-makers in the food industry allocate resources and encourage more consumers for social commerce. Several managerial insights were discussed.

KEY WORDS

consumer purchase, social commerce, food products, COVID-19

10.2478/emj-2023-0023

Introduction

The global crisis shaped by the COVID-19 pandemic shook the world, restricting people's mobility and activities when the government actively imposed border controls to help lessen the virus transmission (Tong et al., 2021; Din et al., 2022). Economic activities, such as business operations, social gatherings, and educational learning, were disrupted by the call for strict adherence to health protocols in combating the pandemic (Ocampo & Yamagishi, 2020; Benton et al., 2021). Shopping is non-exempt to those perturbed activities where consumer preferences have switched

Pijo, H., Aguilar, A., Catarongan, M. A., Orioque, J., Atibing, N. M., Wenceslao, Ch., Evangelista, S. S., Aro, J. L., Maturan, F., Yamagishi, K., & Ocampo, L. (2023). Methodology of an interpretive structural map construction for social commerce success. *Engineering Management in Production and Services, 15*(3), 101-114. doi: 10.2478/emj-2023-0023

abruptly from offline (i.e., going to malls or physical shops) to online purchases (Kulkarni & Barge, 2020). To safely meet people's consumption requirements, especially for food products, the population of buyers and sellers shifted to using electronic commerce (e-commerce) platforms (Sheth, 2020; Lin et al., 2021). To this end, e-commerce, which pertains to the buying and selling activity of various goods on online platforms (Kwilinski et al., 2019), has since become prominent in the market with the advent of COVID-19 (Guo et al., 2021; Dixon, 2022). With this trend, an overflowing number of consumers was noticed on various online platforms, consequently driving e-commerce to evolve into a customer-oriented social commerce (Nacar & Ozdemir, 2022; Kim, 2020). Social commerce is leading the future of e-commerce (Attar et al., 2021).

Social commerce is a type of commerce mediated by social networking sites (e.g., Facebook, Instagram, and Twitter) and involves the convergence of online and offline environments (Yacob et al., 2021). More consumers use social networking sites to learn about marketing, selling, comparing, curating, buying, and sharing goods and services in online and offline marketplaces and communities (Zhou et al., 2013). Thus, social commerce increases quickly in various emerging markets and developing economies because of the changes in the information and communication technology (ICT) landscape (Arceño et al., 2022). Despite the prominence of food-selling platforms, there are many challenges faced by micro, small, and medium enterprises (MSMEs) when it comes to seamlessness in social commerce (Savrul, 2014), such as food enterprise competitiveness (Kukharuk & Gavrysh, 2019), rapid business model iteration, and the overwhelming flow advantage of giant enterprises (Chen et al., 2021). Meanwhile, many social commerce enterprises are also experiencing issues during their rapid expansion, such as unbalanced development and resource allocation (Chen et al., 2021). These issues significantly affect the competitiveness and adaptability of social commerce enterprises, making the whole industry relatively unstable.

To address these problems and improve the survivability of enterprises, it is imperative to understand the success factors affecting consumer purchase decisions on social commerce platforms (i.e., food reliability, product quality, safety, and convenience) (Hong et al., 2021; Prasetyo et al., 2021). While many studies have been made to understand the influence of these success factors on the buyer's decision to buy food online, limited attention is given to these priority factors, which are generally analysed in isolation, particularly in narrowing the context of social commerce. Such an approach does not fully address the inherent complex interrelationships of these factors, which may result in counterintuitive insights. Nevertheless, Arceño et al. (2022) reported an attempt to evaluate the factors affecting consumer purchase intention to purchase food products on Facebook platforms using a Decision-Making Trial and Evaluation Laboratory (DEMATEL). On the other hand, Guerrero et al. (2023) examined the barriers (i.e., which can be framed as factors) of online shopping in the Philippines, both from buyers' and sellers' perspectives, using interpretive structural modelling. Both attempts stem from their review of many empirical studies suggesting the causal relationships among these factors. Despite their reports, the context of social commerce, which combines offline and online environments, is left unattended. Hence, evaluating the interrelationships among factors that affect consumers' decision to purchase food products and subsequently deriving the resulting priority factors are an exciting agenda that requires investigation in a social commerce environment.

Thus, this work examines the complex interrelationships among the success factors of social commerce success and builds a structural map that effectively portrays their inherent transitivity, thereby offering rich information for practitioners. Due to its efficacy demonstrated in vast applications, the interpretive structural modelling (ISM) approach is adopted as the overarching methodology to gain insights into the complexity of the relationships among success factors, effectively advancing the insights of Arceño et al. (2022) for a social commerce context. The ISM is an established methodological framework for developing hierarchical and contextual relationships among the elements of a system. It is a "systematic application of some elementary notions of graph theory in such a way that theoretical, conceptual, and computational leverage is exploited to efficiently construct a directed graph, or network representation, of the complex pattern of a contextual relationship among a set of elements" (Malone, 1975). It offers a visual systems model derived from an unstructured mental model of complex relationships among elements in a system. On the other hand, a cross-impact matrix multiplication applied to classification, originally known as the Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (MICMAC), is introduced to analyse the interaction

of success factors and recognise the most relevant ones. The efficacy of the ISM-MICMAC has led to its adoption in various applications, including, but not limited to, the analysis of lean six sigma barriers (Vinodh & Asokan, 2018), evaluation of manufacturing implementation factors (Sonar et al., 2020), assessment of the obstacles to implementing big data analytics (Dehkhodaei et al., 2023), examining buying behaviour of millennials for secondhand clothing (Medalla et al., 2020), evaluating the factors of research productivity (Ocampo et al., 2022), analysis of the challenges for adopting the Internet of Things (Janssen et al., 2019), and modelling the challenges of university technology transfer (Quiñones et al., 2020). Compared to the DEMATEL used by Arceño et al. (2022) in a similar study of e-commerce platforms, the ISM-MICMAC analysis offers at least two specific advantages: (1) it relaxes the contextual relationships among factors, rather than strict causal relationships, and (2) it builds a more organised hierarchical structure of the factors, portraying an effective representation of their relationships that can be better understood by decision-makers and practitioners. Thus, a comprehensive evaluation of the social commerce success factors by integrating ISM-MICMAC analysis informs practical insights that will help food MSMEs advance their social commerce models.

The remainder of this paper is structured as follows. Section 2 discusses the role of social commerce in online food delivery (OFD) systems and the factors influencing consumer purchase decisions in social commerce, while Section 3 presents the preliminary concepts of the ISM-MICMAC analysis. Section 4 outlines the application of the ISM-MICMAC analysis in structuring the success factors of adopting social commerce. Section 5 offers some managerial implications of the findings, while Section 6 ends with some concluding remarks and directions for future work.

1. Literature review

1.1. Role of social commerce in food delivery systems

Online food delivery (OFD) systems have recently become a global trend. The worldwide revenue of the OFD market is expected to be USD 1465.6 billion by 2027 (Dixon, 2022). Convenience is one of the main reasons consumers buy food online (Chai & Yat, 2019). During the global COVID-19 pandemic, the advantages of OFD have become more evident as it enhanced the accessibility of ready-made meals while enabling food providers to continue their operations (Li et al., 2020). Thus, the online food industry has cultivated various ways to elevate its services to cater to the increasing demand and remain competitive in the market, such as offering hefty discounts and developing effective promotional campaigns (Li et al., 2020). Accordingly, OFD has shifted from Restaurant-to-Consumer delivery to Platform-to-Consumer delivery, wherein the order is made through the food establishment's online platform or third-party platforms (Pal et al., 2022). These third-party platforms vary from country to country. For instance, in China, Meituan is the leading food delivery app (Culture Yard, 2022), while Just Eat Takeaway dominates the United Kingdom's food delivery market (Startups of London, 2022). The Philippines' OFD industry has been dominated by Grab and Food Panda (Statista Research Department, 2023). Thus, it is evident that the OFD industry has shown enhanced proactivity in expanding into new markets and shaping consumer eating habits. Due to the increasing demand, the role of social media in augmenting the OFD industry through advertisement and promotional campaigns has gained recognition in the current literature (Bhattacharyya & Bose, 2020). Moreover, there is an increasing trend in utilising social media platforms as a medium for food providers and consumers to engage in OFD services (Attar et al., 2021).

In recent years, social commerce has led the future of e-commerce (Attar et al., 2022). Nacar and Ozdemir (2022) emphasised that adopting social media in commercial transactions has notably transformed the traditional product value creation, marketing, branding, and production and purchasing activities of various businesses. Furthermore, social commerce allows seamless communication between sellers and buyers as a result of the communication-effective and user-centred designs enforced by social media platforms (Huang & Benyoucef, 2013); thus, making it convenient for both parties to conduct buy and sell transactions (Liao et al., 2021). Recent reports reveal that social media influenced purchases for 74 % of customers, with customers comparing prices and promotions (Beer, 2018). Thus, marketers have recently started leveraging social networking sites to promote their products and facilitate commercial transactions through the channel, effectively boost-

ing social commerce (Bhattacharyya & Bose, 2020). Accordingly, Facebook is the most widely used social networking site among individuals and businesses (Bhattacharyya & Bose, 2020). Facebook has been used by more than 86 % of US marketers for advertising in 2019. Due to its popularity in practice, academic research has started showing interest in understanding the role of Facebook, particularly in user consumption decisions. For instance, Bhattacharyya and Bose (2020) analysed the influence of Facebook interactions (e.g., likes, comments) on the purchase behaviours of consumers on a linked e-commerce site, while Al-Adwan and Kokash (2019) explored the driving forces of Facebook social commerce. On the other hand, Abuhashesh et al. (2021) investigated the effect of culture on consumer attitudes toward Facebook advertising. Meanwhile, the social media platform added various functions that allowed customers to comment on and rate their products and services (Nacar & Ozdemir, 2022). For instance, the Marketplace feature of Facebook, a function added in January 2018, has created a communication channel for buyers and sellers to interact with each other (Redfearn, 2019). Due to the straightforward and practical function of social media platforms, MSMEs have used these platforms to establish their business in terms of managing customer relationships and online presence (Handayani & Lindianigrum, 2011; He & Harris, 2020).

1.2. Factors influencing consumer purchase decisions in social commerce

The development and availability of online food purchasing through social media and social commerce combined with the busy schedule demand more expansive research for better understanding (Saad, 2021). Thus, various studies have ventured into determining the factors that influence consumer purchase decisions in social commerce. For instance, Cho and Sagynov (2015) determined such factors as product information, price, perceived product or service quality, usefulness, and convenience, including service quality offered by the seller. Using factor and regression analysis and structural equation modelling, it was found in their empirical analysis that perceived usefulness, perceived ease of use and trust had a significant effect on the behavioural intention to shop online. Another study (Moslehpour et al., 2021) showed that social media marketing, trust, and brand image affect the consumers' purchase intention. But among these factors, entertainment and word-of-mouth bring the most significant effect on a consumer's purchase intention. Hence, trust and brand image mediate the relationship between social media marketing and purchase intention. Trust and brand image can significantly amplify the influence of each variable on the consumer's purchase intention. Thereby, each factor significantly affects one another. Francioni et al. (2022) emphasised the differences in purchasing food online based on gender. In general, perceived healthiness, quarantine procedures, perceived hygiene, perceived ease of app use and attitude significantly influence continuance intention. Furthermore, it was also revealed that perceived healthiness, quarantine procedures, and perceived hygiene mainly influence male consumers' continuance intention.

Conversely, female customers' intention to purchase online is predicted by perceived healthiness and attitude, with respondents representing young customers aged 18–29. Another work by Shankar et al. (2022) using a qualitative and exploratory approach concluded the factors important to consumers in ordering food online through social media. Results showed that delivery time, service quality, price and condition of food delivered are the first factors that directly affect the success of online food delivery. Moreover, delivery tracking service and the attitude of a delivery person are found to constitute the second factor and are considered indirect factors. On the other hand, Faraoni et al. (2019) explored the antecedents of loyalty among consumers in e-commerce. They found that one of the critical factors affecting consumers' trust in the sellers is how the sellers handle the information provided during the transaction.

In particular, some of the frequent factors documented in the empirical studies of various scholars regarding these factors are the service quality, delivery time, electronic word of mouth (eWOM), pricing and condition of the food provided, brand familiarity, and the attitude of delivery people (Jiang et al., 2021; Hong et al., 2021; Prasetyo et al., 2021). Discussions of these research findings mentioned that the identified factors are considered crucial in food social commerce, especially in influencing the buying preference of food consumers online. Moreover, social interactions through eWOM emanate the prestige of the product and brand (Lim et al., 2022; Liu, 2021). Keeping abreast in strategising marketing is necessary to attract more customers (Kim et al., 2015; Lim et al., 2022). This affects people's cognisance of their self-performance (Bone, 1995), including some affective elements broadly known to be highly efficient to

both businesses and customers. As a result, uplifting and implementing strategies relating to the emotional factors associated with service quality must be designed by organisations to constantly build a strong connection with their customers (Qiu et al., 2019). Furthermore, the domain literature highlights some significant links between service quality, food quality, customer satisfaction, and perceived value in the context of customer satisfaction with virtual food ordering services and stresses the importance of quality in both service and food as it relates to customer satisfaction (Uzir et al., 2021). In addition, customer value positively influences buying intention (Su et al., 2019). Arceño et al. (2022) attempted to holistically evaluate these factors, contextualised in Facebook e-commerce platforms and found the criticality of reliability, food product quality and safety, and convenience. While these interrelationships are highlighted in the literature, evaluating social commerce success factors in light of these interrelationships remains a gap. Since social commerce platforms became prominent when buying activities were limited to online and no-contact interactions, MSMEs need to advance their initiatives to get a competitive edge when the stringent restrictions return to normal operations.

2. Preliminary concepts of interpretive structural modelling and MICMAC analysis

The significance of interpretive structural modelling lies in developing a map of complex relationships among many elements to construct a directed graph or network representation. It graphically identifies the relationships among elements to better understand their relationship structures. The foundations of the ISM were formulated by Harary et al. (1965). Meanwhile, the philosophical basis for a better understanding of ISM was presented by Warfield (1973). The ISM is a context-free technique best utilised when the gathered data is susceptible to human subjectivity. The mathematical basis of the ISM can be found in Harary et al. (1965) and is not discussed here for brevity. The foundation of the approach lies in utilising the expertise of people having knowledge in the desired field and then breaking down a complex system into several subsystems and establishing a multilevel structural model. The following are the steps taken throughout the study.

Step 1. Identify the system elements for analysis. These elements must be homogeneous with respect to the concept under investigation (e.g., factors of consumer purchase decisions). This process can be accomplished through various means, including but not limited to reviewing literature in the domain, conducting surveys, facilitating focus group discussions, or employing a combination of these methods. Since this work builds upon the factors identified by Arceño et al. (2022), 13 social commerce success factors were considered under evaluation.

Step 2. Construct a structural self-interaction matrix (SSIM) for each expert when a small group of domain experts is individually tasked to establish the structural model. Alternatively, when a group reaches a consensus through a group decision-making process, a single SSIM is generated to represent the collective decision. These experts are asked to evaluate the contextual relationship between the two elements. Four notations are used to describe the relation between a pair of elements:

- V for the relation from i to j but not in both directions;
- A for the relation from j to i but not in both directions;
- X for the relation from i to j and from j to i (i.e., both directions);
- O for the no relation that exists between i to j.

Step 3. Transform the SSIM into a binary matrix representation using the following relation R:

- V implies that $i\mathrm{R}j = 1$ and $j\mathrm{R}i = 0$;
- A implies that $i\mathrm{R}j = 0$ and $j\mathrm{R}i = 1$;
- X implies that $i\mathrm{R}j = 1$ and $j\mathrm{R}i = 1$;
- O implies that $i\mathrm{R}j = 0$ and $j\mathrm{R}i = 0$.

Step 4. Generate an initial reachability matrix $R = \left(r_{ij}\right)_{m\times m}$ for each SSIM using Equation (1).

$$R = A + I \tag{1}$$

where $A = \left(a_{ij}\right)_{m\times m}$ is an adjacency matrix where $a_{ij} = \begin{cases} 1 & \text{if} \quad i\mathrm{R}j = 1 \\ 0 & \text{if} \quad i\mathrm{R}j = 0 \end{cases}$; and I is an identity matrix with a size $m \times m$.

Step 5. Obtain an aggregate initial reachability matrix. When expert decision-makers individually generate an SSIM, the aggregation of the resulting initial reachability matrices is carried out via the majority rule (Sushil, 2018). A majority rule is a decision-making principle that chooses alternatives supported by a majority, which means they have more than half of the total votes. Consider an

aggregate reachability matrix $\tilde{R} = (\tilde{r}_{ij})_{m\times m}$. Thus, $\tilde{r}_{ij} = 1$ if the majority of experts favour the existence of the contextual relationship from element i to element j. Otherwise, $\tilde{r}_{ij} = 0$. Implementing the majority decision rule is necessary as it allows the aggregation of expert views, and when applied, it indicates that the number of supporters for a proposal outweighs its opponents. A more stringent requirement could be established, demanding that at least two-thirds of the experts declare $r_{ij} = 1$ (Sushil, 2018). In the event of the expert group reaching a consensus, this step is omitted.

Step 6. Produce the final reachability matrix $R^* = (r_{ij}^*)_{m\times m}$ by checking transitive links or relationships. It satisfies that if $\tilde{r}_{ij} = 1$ and $\tilde{r}_{ik} = 1$, then $r_{ik}^* = 1$, for elements i, j, and k. Warshall's algorithm is widely employed for enumerating transitive links, i.e., generating the transitive closure of a directed graph (Warshall, 1962).

Step 7. Determine the reachability set R_i and antecedent set A_i $(\forall i, j)$ from R^*. The reachability set R_i is defined as

$$R_i = \{i, j: r_{ij}^* = 1, j = 1, \dots, i-1, i+1, \dots, m\}. \quad (2)$$

On the other hand,

$$A_i = \{i, j: r_{ij}^* = 1, i = 1, \dots, j-1, j+1, \dots, m\}. \quad (3)$$

The intersection I_i set is defined as

$$I_i = R_i \cap A_i \quad (4)$$

The driving power D_i is simply the cardinality of R_i, denoted by $D_i = |R_i|$. The dependence power P_i, on the other hand, is defined as $P_i = |A_i|$.

Step 8. Perform level partitioning. Organising the elements into a hierarchical structure with κ levels offers valuable and practical insights into these elements. In this step, Algorithm 1 outlines the iterations of the partitioning rules.

Algorithm 1. Level partitioning

1. Start.
2. For each i, evaluate R_i and I_i.
3. If $R_i = I_i$, assign i to Level 1.
4. For each j, $j \in \{1, \dots, n\} \setminus i$, evaluate R_i and I_i.
5. If $R_i = I_i$, assign j to Level 2.
6. Repeat Step 3 and Step 4 for all remaining elements until all elements are assigned to $1, \dots, \kappa$ levels.
7. End

Step 9. Create the directed graph by excluding the transitive links. In the digraph, the elements are represented as vertices, and the contextual relationships are depicted as edges. If $r_{ij}^* = 1$, then a directed edge emanates from element i to element j. The construction of the interpretive structural model involves integrating the level partitions established in Step 8.

Step 10. Examine the driving power and the dependence power. As an extension of the ISM, the *Matrice d'Impacts Croisés Multiplication Appliquée á un Classement* (MICMAC) analyses the elements' driving power and dependence power. By constructing a $D_i \times P_i$ map, they are classified into four clusters:

- Elements with high driving power and weak dependence power depict independent elements.
- Elements with strong driving and dependence power depict linkage elements.
- Elements having strong dependence power and weak driving power depict dependent elements.
- Elements having weak driving and weak dependence power depict autonomous elements.

3. APPLICATION OF ISM-MICMAC ANALYSIS

The following are the steps in modelling the relationships of the factors that influence buying preferences of food consumers in social commerce platforms using the ISM-MICMAC analysis.

Step 1. List the factors of social commerce success.

The list of factors in this study is lifted from the factors identified by Arceño et al. (2022) through a focus group discussion with 15 participants. During COVID-19 lockdowns in the Philippines, communities are involved in buying and selling through Facebook social commerce platforms, such as virtual marketplaces and Facebook groups. Each participant is a member of at least one Facebook group for online buying and selling. Presented in Table 1 is the list of identified factors with a brief description and corresponding codes.

Step 2. Construct the individual structural self-interaction matrices.

The same set of participants were asked to judge the relationship among the factors influencing consumers to buy food products through social commerce platforms. They were briefed about the

Tab. 1. Social commerce success factors from Arceño et al. (2022)

Code	Factors	Description
F1	Food product presentation	The degree to which the product is posted online in terms of appearance and description
F2	eWOM	The number of positive comments from customers to the posted product online, including shares and likes
F3	Cost	The unit cost of the product, including delivery costs
F4	Reliability	The degree of the customer's perception of the integrity, reliability, responsiveness, trust, and perceived risk of the seller
F5	Return/refund policy	The seller's perceived willingness to accommodate product returns due to defects and non-conformity with the promised specifications
F6	Timeliness	The perceived degree of seller's reliability in terms of food product delivery time
F7	Consumer relation	The seller's perceived degree of receptiveness and engagement in answering customer queries
F8	Food product quality and safety	The degree of conformity of the food product in relation to taste, content, and safety
F9	Internet connectivity	The speed of the Internet connectivity of the customer in purchasing the food product online
F10	Convenience	The degree of ease of use in ordering the food product
F11	Social influence	The level at which the presence or action of others modifies an individual's attitude, beliefs, or behaviour
F12	Data privacy policy	The degree of confidentiality of the personal information of the customer
F13	Public health concern	The degree to which public health and safety protocols are observed in food preparation and delivery

Tab. 2. A sample structural self-interaction matrix

Factors	F13	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2
F1	O	O	V	O	O	A	V	X	O	V	X	V
F2	A	A	X	A	X	X	X	X	X	A	X	
F3	X	X	A	A	A	X	X	X	X	X		
F4	X	X	X	X	X	X	X	X	X			
F5	O	X	X	X	X	O	X	O				
F6	O	O	V	O	A	O	V					
F7	A	A	V	V	A	A						
F8	X	O	A	O	O							
F9	O	O	A	X								
F10	O	O	V									
F11	A	A										
F12	O											

study and the corresponding questionnaire, which was drafted in the context of the ISM. The questionnaire was distributed to the experts, and questions regarding the questionnaire were immediately addressed. A corresponding SSIM was constructed for each participant wherein the identified relationship is rated either V, A, X, or O, discussed in Step 2 of Section 3. A sample of an SSIM is presented in Table 2.

Step 3. Convert the structural self-interaction matrices into initial reachability matrices.

An initial reachability matrix was constructed for each SSIM, as in Step 3 of Section 2. A sample is shown in Table 3.

Step 4. Aggregate the initial reachability matrices.

In this study, each participant is assigned an equal weight which implies that the judgments of all participants are equally significant. The aggregation of the initial reachability matrices assumes the following. The aggregate initial reachability matrix is denoted as $\tilde{R} = \left(\tilde{r}_{ij}\right)_{m\times m}$ and constructed using the

Tab. 3. Initial reachability matrix sample

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
F1	1	1	1	1	0	1	1	0	0	0	1	0	0
F2	0	1	1	0	1	1	1	1	1	0	1	0	0
F3	1	1	1	1	1	1	1	1	0	0	0	1	1
F4	0	1	1	1	1	1	1	1	1	1	1	1	1
F5	0	1	1	1	1	0	1	0	1	1	1	1	0
F6	1	1	1	1	0	1	1	0	0	0	1	0	0
F7	0	1	1	1	1	0	1	0	0	1	1	0	0
F8	1	1	1	1	0	0	1	1	0	0	0	0	1
F9	0	1	1	1	1	1	1	0	1	1	0	0	0
F10	0	1	1	1	1	0	0	0	1	1	1	0	0
F11	0	1	1	1	1	0	0	1	1	0	1	0	0
F12	0	1	1	1	1	0	1	0	0	0	1	1	0
F13	0	1	1	1	0	0	1	1	0	0	1	0	1

Tab. 4. Aggregate initial reachability matrix

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
F1	1	1	0	0	0	0	1	0	0	0	1	0	0
F2	0	1	0	1	0	0	1	0	0	0	1	0	0
F3	0	0	1	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	1	1	0	1	1	0	1	1	0	1
F5	0	0	0	1	1	0	1	0	0	0	0	0	0
F6	0	1	0	1	0	1	1	0	0	1	0	0	0
F7	0	0	0	0	0	0	1	0	0	0	1	0	0
F8	1	0	1	1	0	0	0	1	0	0	0	0	1
F9	0	0	0	0	0	0	1	0	1	1	0	0	0
F10	0	0	0	0	0	0	0	0	0	1	1	0	0
F11	0	0	0	0	0	0	1	1	0	0	1	0	0
F12	0	1	0	1	0	0	1	0	0	0	0	1	0
F13	0	0	0	1	0	0	0	1	0	0	1	0	1

Tab. 5. Final reachability matrix

Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
F1	1	1	1*	1*	1*	0	1	1*	0	1*	1	0	1*
F2	1*	1	1*	1	1*	0	1	1*	0	1*	1	0	1*
F3	0	0	1	0	0	0	0	0	0	0	0	0	0
F4	1*	1*	1*	1	1	0	1	1	0	1	1	0	1
F5	1*	1*	1*	1	1	0	1	1*	0	1*	1*	0	1*
F6	1*	1	1*	1	1*	1	1	1*	0	1	1*	0	1*
F7	1*	1*	1*	1*	1*	0	1	1*	0	1*	1	0	1*
F8	1	1*	1	1	1*	0	1*	1	0	1*	1*	0	1
F9	1*	1*	1*	1*	1*	0	1	1*	1	1	1*	0	1*
F10	1*	1*	1*	1*	1*	0	1*	1*	0	1	1	0	1*
F11	1*	1*	1*	1*	1*	0	1	1	0	1*	1	0	1*
F12	1*	1	1*	1	1*	0	1	1*	0	1*	1*	1	1*
F13	1*	1*	1*	1	1*	0	1*	1	0	1*	1	0	1

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supermajority rule (i.e., 75% of all participants), which is set to filter out weak relationships. Let r_{ij}^k be the resulting judgment elicited by the kth participant on the contextual relationship emanating from the ith factor to the jth factor. If $\sum_{k=1}^{K} r_{ij}^k \geq 0.75K$, then $\tilde{r}_{ij} = 1$. Otherwise, $\tilde{r}_{ij} = 0$. Table 4 features the aggregate initial reachability matrix.

Step 5. Obtain the final reachability matrix.

Using Step 6 of Section 3 and Warshall's algorithm, the final reachability matrix $R^* = \left(r_{ij}^*\right)_{m\times m}$ is obtained. Table 5 presents the final reachability matrix wherein "1*" indicates a transitive relationship.

Step 6. Construct level partitions and draw the final interpretive structural map.

Using Algorithm 1 discussed in Section 3 to determine the level of each factor in the hierarchy and the aggregate initial reachability matrix, the final interpretive structural map was constructed, as presented in Table 4 (Fig. 1).

Step 7. Perform the MICMAC analysis.

The MICMAC analysis is employed by calculating the driving power D_i and dependence power P_i. The graphical representation of D_i and P_i of factor i $(\forall i = 1, \ldots, m)$, as discussed in Step 10 of Section 3, is presented in Fig. 2.

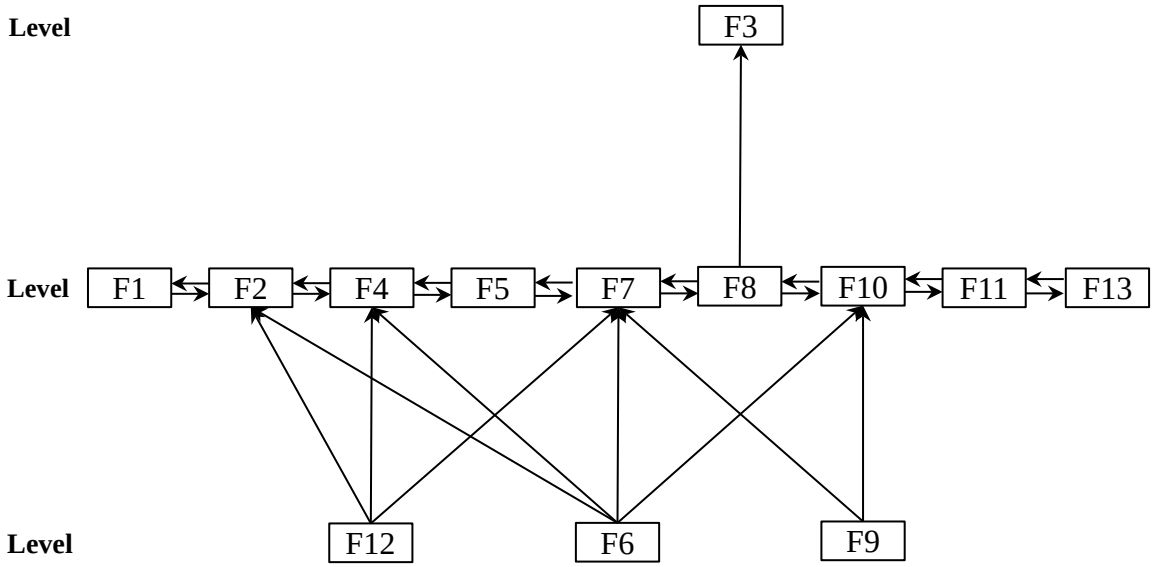

Fig. 1. Interpretive structural model of contextual relationships

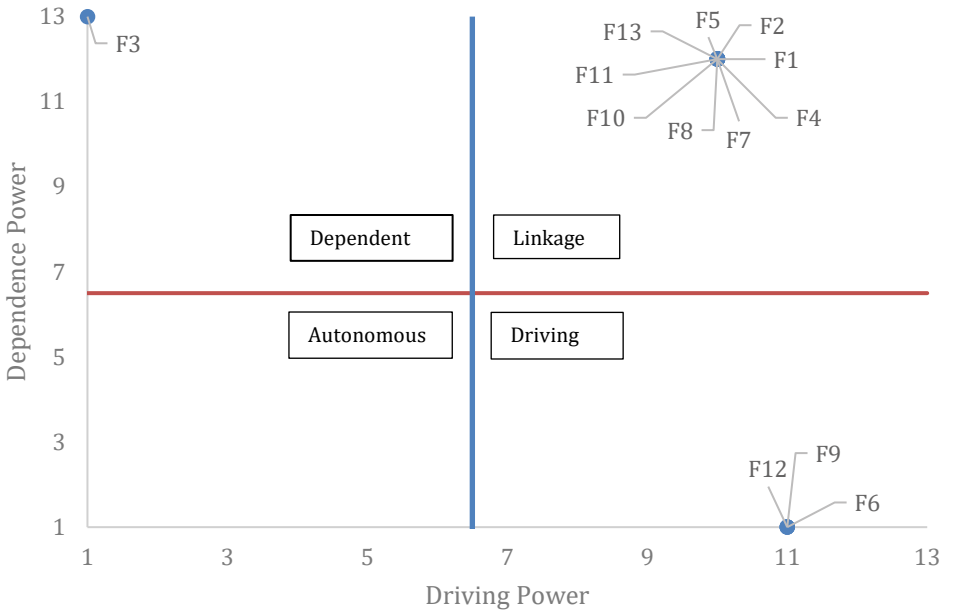

Fig. 2. MICMAC analysis map

4. Results and managerial implications

The factors that impact the purchase behaviours of online consumers in e-commerce platforms have been thoroughly explored in the literature. However, significant gaps remain in the context of food social commerce, which requires the integration of both online and offline environments, investigating the agenda of determining the factors that drive consumers to purchase food and exploring the interrelationships among these factors. To address these gaps, this work (1) conducted an FGD to determine the critical factors that define purchase behaviour in the context of food social commerce and (2) employed the ISM-MICMAC analysis to define the holistic relationships among the factors that affect the intention of the consumers to purchase food via social commerce. The methodology follows the procedure inherent in ISM-MICMAC analysis under group decision-making. First, 15 structural self-interaction matrices were constructed and transformed into initial reachability matrices. The initial reachability matrices were aggregated via a supermajority rule, and then the final reachability matrix defined the transitive or indirect relationships among the identified factors. The interpretive structural model of the contextual relationships was constructed using the aggregate initial reachability matrix and levels of each factor as defined using Algorithm 1. Finally, the MICMAC analysis is carried out wherein the factors are categorised depending on their driving and dependence powers.

As shown in the interpretive structural model (Fig. 1), the factors that impact consumers' buying intention in food social commerce are arranged in three levels in a hierarchical structure. Those at the lower level of the hierarchy drive the factors at the upper levels. Cost is the only factor under Level 1. Food product presentation, eWOM, reliability, return/policy, consumer relation, food product quality, safety, convenience, social influence, and public health concerns made up the driving factors in Level 2. Moreover, timeliness, Internet connectivity, and data privacy policy are the main driving factors that appeared at Level 3. These findings imply that timeliness, Internet connectivity, and data privacy policy drive most of the other factors and focusing the resources on augmenting these factors consequently improves other factors. Further analysis was performed using the MICMAC analysis. Implementing MICMAC reveals nine factors that belong to the linkage cluster: food product presentation, eWOM reliability, return/refund policy, consumer relation, food product quality and safety, convenience, social influence, and public health concern. All factors in the linkage cluster have a strong driving power of ten and a strong dependence power of twelve, as presented in Fig. 2. These factors are unstable, and any decision taken in response to them will affect others and feedback on themselves.

On the other hand, the three driving factors, i.e., timeliness (F6), Internet connectivity (F9), and data privacy policy (F12), dominate consumer decisions to buy food products on social commerce. The driving factors, such as data privacy policy, Internet connectivity, and timeliness, are identified as having independent characteristics. These factors have high driving power but low dependence power. Thus, these are substantial driving factors and may be treated as crucial among all driving factors, considering that they are the most important causative agents influencing consumers' decisions in purchasing food via social commerce platforms. Timeliness, with a driving power of eleven and a dependence power of one, directly involves four driving factors (i.e., eWOM, reliability, consumer relation, and convenience). On the other hand, Internet connectivity having a driving power of eleven and a dependence power of one directly affects two driving factors (i.e., consumer relationship and convenience). Furthermore, the data privacy policy, with a driving power of eleven and a dependence power of one, affects three driving factors (i.e., eWOM, reliability, and consumer relation). These findings are inconsistent with those of Arceño et al. (2022), who highlighted reliability, food product quality and safety, and convenience in e-commerce. These inconsistencies may be viewed from the differences between e-commerce and social commerce, where the latter emphasises the presence of social media platforms that require Internet connectivity and data privacy. Since most consumers have social media accounts, particularly in the case of Facebook as a dominant social media networking site, the timeliness of delivering the order food products entices them to avail social commerce. Given these insights, stakeholders and decision-makers should focus on this cluster, as driving factors have a significant influence over other factors influencing consumer decisions to buy food products in social commerce.

The findings of the ISM-MICMAC analysis offer invaluable insights for MSMEs, which are dominant in the food product market on social commerce. In this section, "driving" factors are emphasised since

they are considered the main contributing factors affecting the consumer's decision to purchase food online. High consideration of these driving factors would increase sales of MSMEs. Investments in these driving factors would yield an efficient allocation of organisational resources. One of the main factors influencing consumers' decision to buy food products on social commerce is timeliness, which is the capability of the sellers to prepare and deliver the food on time. This result is consistent with the findings of Jiang et al. (2021), wherein they highlighted the critical role of timeliness in satisfying consumers in food e-commerce. Thus, sellers in social commerce should focus their resources on developing initiatives that improve timeliness. These initiatives can include improving the overall service chain from ordering raw materials (e.g., selecting suppliers who deliver goods timely) to processing food (e.g., efficient scheduling of the cooks) until providing the food to the consumers. Sellers may enhance their transport capacity (e.g., make sure that riders are always available, traffic considerations) or create partnerships with reliable food delivery services that highlight promptness and have an excellent reputation for fast delivery. Moreover, timeliness can be improved by being attentive on social platforms to respond rapidly to customers' requests and inquiries.

Another key factor that sellers in food social commerce should give attention to is the policy on data privacy. In any online transaction, personal information is given by the consumer to the seller, and protecting this information would increase consumer confidence, trust, and loyalty in social commerce platforms, as pointed out by Faraoni et al. (2019). During the food ordering and delivery process, consumer details (e.g., contact information, address, and social media profiles) should be protected to avoid data leaks and possible identity theft, fraud, or unauthorised access to individuals' personal lives. Moreover, posting product reviews or screenshots as proof of consumer legitimacy should be avoided without their consent. To augment data privacy and for consumers to feel safe in providing information, sellers should collect only the data that is necessary for the transaction, partner with trusted payment processors that have complied with the security standards and develop an incident response plan for remedial measures in case of such events as data leaks. Meanwhile, the Internet connectivity of consumers as they purchase online is also relevant. Slow Internet performance becomes concerning when it inconveniences consumers during the purchase transaction, resulting in discontinued purchases. Not only the consumers but also the sellers encounter issues during their business operations due to poor Internet connection. However, this problem is out of the scope of the sellers' control. Hence, the only way to disregard slow Internet as a hindrance to purchasing is for the sellers to reduce information search. If sufficient information is provided in the social media post for the product to be sold, additional tasks for information search of the sellers may not be necessary. Such information may include product features, attributes, specifications, warranty and services, price, location meet-up, and payment information. By providing this information, trivial tasks for the sellers that require an Internet connection, such as replying to customer queries on the social media platform, will be eliminated. Furthermore, additional contact information of the seller, such as phone number and business email, may be included in the social media post. Buyers may use this contact information when they cannot access the social media platform due to slow Internet connectivity.

Conclusion and future works

Factors that need to be considered in the social commerce of food products play an essential role in digital entrepreneurship, innovation, and product quality and safety. Due to its significant impact on socio-economic development, current literature has examined how certain factors influence consumers' decisions in purchasing food on social commerce. A substantial list of the factors that drive consumers' decisions to purchase food in e-commerce has been established.

However, the domain literature has not addressed the possible relationships between the identified driving factors of consumers' decisions to purchase food in social commerce context. While empirical evidence reported that the identified driving factors influence consumers' decision to purchase food in social commerce, it is important to consider that these driving factors can impact other driving factors due to their loosely defined boundaries, which is crucial in developing insights for decision making for MSMEs to upgrade their food product quality and safety as well as to reach numerous consumers, increase in sales and profits, and thus, improvement of socio-economic development can gradually be felt in a particular community.

This work adopts a list of 13 relevant driving factors from a previously reported study. The ISM and MICMAC analyses were utilised to determine the possible relationships between driving factors due to the subjectivity of the identified driving factors and the notion that evaluating the interrelationships reflects an expert judgment. The ISM portrays a clear overview of the complex relationships of the driving factors of social commerce success in a manner that establishes a hierarchical structure in determining those factors that are more significant in purchasing food in social commerce. The ISM-MICMAC analysis reveals that most driving factors are categorised as linkage variables that MSMEs must oversee in their food product presentation, quality, safety, and digital marketing strategies in social commerce. As these driving factors have high dependence and driving powers, compromising one driver in this category changes the overall structure of the network of driving factors of consumers' decision to purchase food on social commerce. Furthermore, three driving factors (i.e., timeliness, Internet connectivity, and data privacy policy) identified as independent variables are also crucial since addressing these driving factors would also address other driving factors. Conversely, the cost factor is recognised as the dependent variable, while no autonomous factor has been identified. The results of this work contribute meaningfully to the literature as it provides significant insights that would help better understand the factors influencing the consumers' decision to purchase food on social commerce. These results would aid MSMEs, especially the local online sellers, in maintaining timeliness in their transactions by streamlining the overall service chain, safeguarding consumers' private data by keeping only the minimal required information to process the transaction, and upholding efficiency in consumer communication to maximise Internet connectivity, especially in localities with slow Internet performance.

Nevertheless, this work contains some limitations. Few experts eliciting judgments in the ISM-MICMAC analysis can be considered as the basis for future studies. Since the consumers are all from the Philippines, their judgments may not reflect other consumers across other countries with different cultures, different exposure levels to social commerce, and various consumption attitudes. Moreover, the interrelationships put forward in this study can be considered conceptual, reflecting the knowledge and experience of experts. However, an empirical analysis that tests how actual data support such relationships may be an interesting agenda for future work. With this, statistical modelling (i.e., factor analysis and structural equation modelling) may be adopted to validate the relationships between the driving factors discussed in this work. Also, the decisions of consumers to purchase food on social commerce might be influenced by intergenerational variances. It would be valuable for future research to explore the contrasting behaviours of younger consumers and their older counterparts in social commerce. Lastly, a parallel analysis that would espouse fuzzy cognitive mapping in examining how an increase in one factor increases other factors is an important future agenda to aid in the allocation decisions of sellers.

Literature

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