Suggestions for Integrated BSC-DEA Implementation in the Industry 4.0 Company

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ABSTRACT

Purpose: The implementation of the integrated BSC-DEA model in an Industry 4.0 company involves leveraging advanced technologies to enhance its performance measurement. This approach enables real-time monitoring of KPIs, optimising operational efficiency while ensuring continuous improvement in a rapidly evolving digital environment. By integrating BSC-DEA with Industry 4.0 principles, companies can achieve a more agile and data-driven decision-making process, securing a sustainable competitive advantage.

Methodology/Approach: The integration uses BSC to identify KPIs, which are then applied in the DEA model. This allows an Industry 4.0 company to benchmark performance and optimise resource use through targeted improvements.

Findings: This research overview presents a structured approach to understanding the proposal for applying the integrated BSC-DEA model in an Industry 4.0 company. Continuous feedback, data validation, and periodic reviews ensure that the model facilitates sustainable performance improvement.

Research Limitation/implication: The proposed implementation process requires a substantial commitment of time and resources, along with support from all levels of the Industry 4.0 company.

Originality/Value of paper: The research presented in this paper introduces novel concepts, methodologies, and findings that advance the current state of knowledge. The originality of this work is demonstrated through innovative approaches to existing problems, as well as the analysis and synthesis of diverse ideas to develop new theoretical processes, models, and practical implications.

Category: Research paper

Keywords: Balanced Scorecard; Data Envelopment Analysis; Industry 4.0; process; model

1 INTRODUCTION

The current environment of globalisation and economic turbulence has increased the challenges executives face, and, therefore, there is a critical need for finding effective tools to meet these challenges and good ways accurate methods to assess their companies' performance and financial health.

An innovative integration of the Balanced Scorecard (BSC) and Data Envelopment Analysis (DEA) models represents a major advancement in performance measurement and strategic management. This approach leverages the strengths of powerful management tools to create a more comprehensive and effective system for evaluating and improving the performance of industrial companies.

The BSC developed by Robert Kaplan and David Norton is a strategic planning and management system that helps companies align their business activities with their vision and strategy. It evaluates companies' performance from four traditional perspectives: financial, customer, internal business processes, and learning and growth. However, the latest 4th Generation BSC introduces an external perspective that incorporates social and environmental impact. The environmental impact is added alongside the financial perspective, while the social impact can be placed above the customer perspective. This broader approach reflects the wider influence on society or the community beyond what is captured by the customer perspective (Excitant, 2024). Data Envelopment Analysis, developed by Abraham Charnes, William W. Cooper, and Eduardo Rhodes, on the other hand, is a linear programming methodology used to measure the relative efficiency of decision-making units (DMUs) with multiple inputs and outputs.

The integration of these two methodologies aims to enhance the quantitative aspects of the BSC by incorporating the efficiency measurement capabilities of DEA. This innovative model provides Industry 4.0 companies with the tools to achieve higher quality, drive innovation, and ensure long-term prosperity and growth.

The implementation process of the integrated BSC-DEA model is grounded in general principles and best practices from strategic management, performance measurement, and operations research. It synthesises established methodologies and concepts widely recognised in both academic and professional literature.

1.1 The integration of DEA and BSC methodologies

The integrated BSC-DEA model could improve both models' overall capabilities and reduce each one's faults.

Figure one offers a systematic review of BSC research over three decades since the strategic performance measurement and management tool was originally developed by Kaplan and Norton (1992).

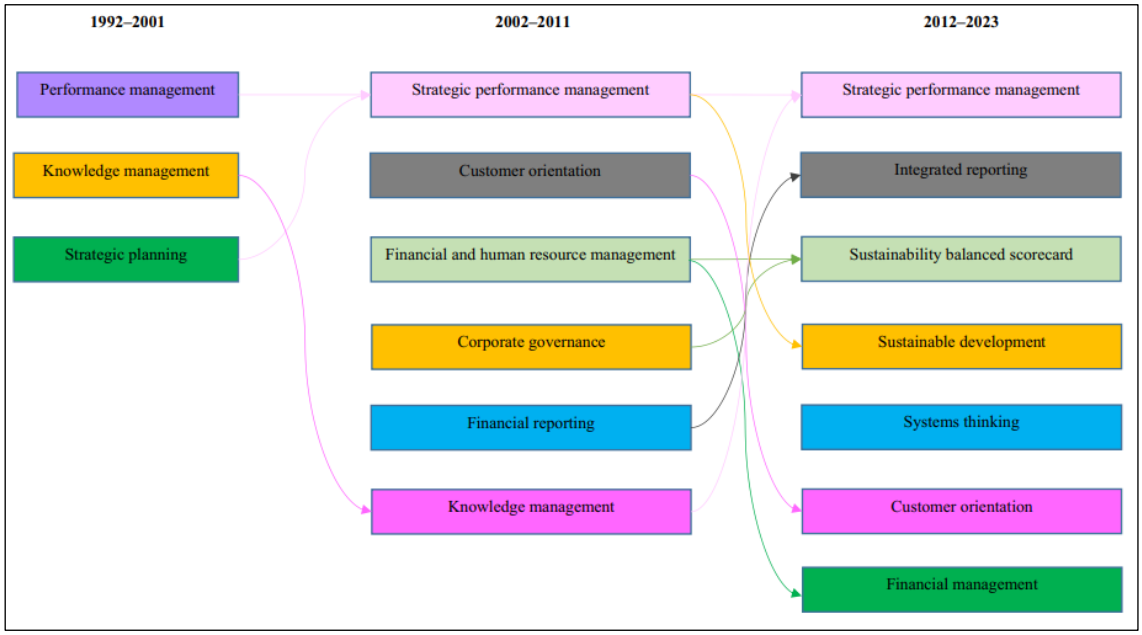

Figure 1 – The evolution of BSC research (Kumar et al., 2022)

Concerns regarding digital transformation have forced manufacturing organisations to rethink their operations and processes to gain a competitive advantage. For several companies, the design and implementation of indicators are deemed crucial for better management and control of emerging concepts and ideas regarding digital technologies. Despite the quick shift towards digital transformation has captured the attention of both the industry and academia, very few efforts have been made to streamline useful indicators able to monitor the implementation of Industry 4.0 technologies. Industrial revolutions represent significant changes in industrial and manufacturing technologies, fundamentally affecting the way companies produce goods and provide services. Each of these revolutions has introduced innovative technologies and processes that increased productivity and transformed the economy (Kumar et al., 2024).

The proposed extended Balanced Scorecard model in the context of Industry 4.0 considers not only the financial and operational performance of the company but also factors of innovation, employee development, and sustainability. This approach enables companies to effectively manage financial health and improve long-term competitiveness in alignment with new market trends and requirements.

Figure 2 shows the details of the proposed DEA-BSC model, which includes six strategies of the latest 4th Generation BSC. This process needs to be executed continuously to help the company reach its goals. The input and the output parameters for the DEA are values of selected key performance indicators (KPIs) (Aryanezhada et al., 2011) that involve the integration of Industry 4. 0 – digital technologies, devices, and processes enable the operation of autonomous manufacturing models capable of functioning in a decentralised decision-making environment with minimal human intervention and capable of collaborating across

the stages of the production process and multiple levels of the supply chain (Sardjono et al., 2021).

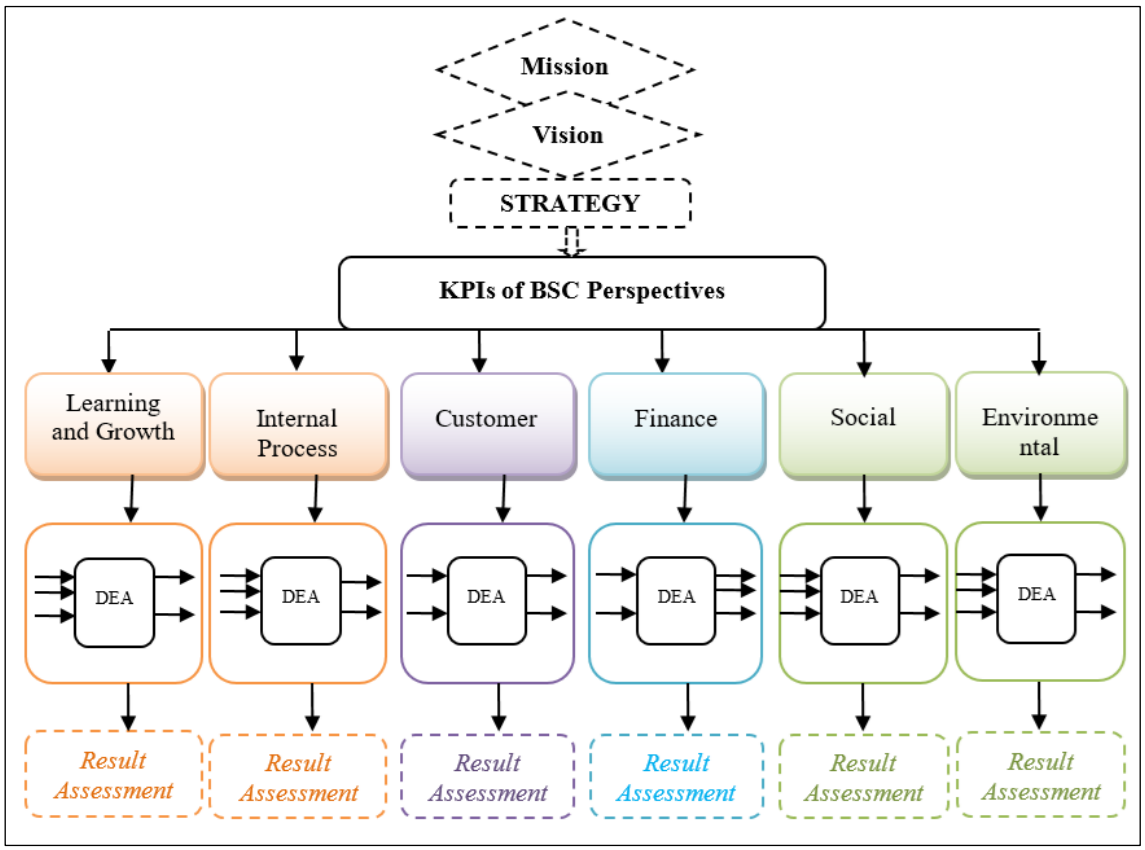

Figure 2 – Illustration of the integrated BSC-DEA model extended by new perspectives

The BSC effectively demonstrates how various components of an Industry 4.0 company contribute to its overall success through a series of clear cause-and-effect relationships. Given this characteristic, we propose that the BSC framework could serve as a valuable foundation for organising multiple interrelated DEA models (Kadárová et al., 2013).

1.2 Approaches to the issue of integration of DEA and BSC methods in the world

The integration DEA and the BSC has garnered attention across various industries and sectors, leading to several approaches being developed globally.

The integrated BSC-DEA model combines the strengths of both methodologies to provide a more comprehensive performance evaluation system. Figure 3 shows its application across various industries.

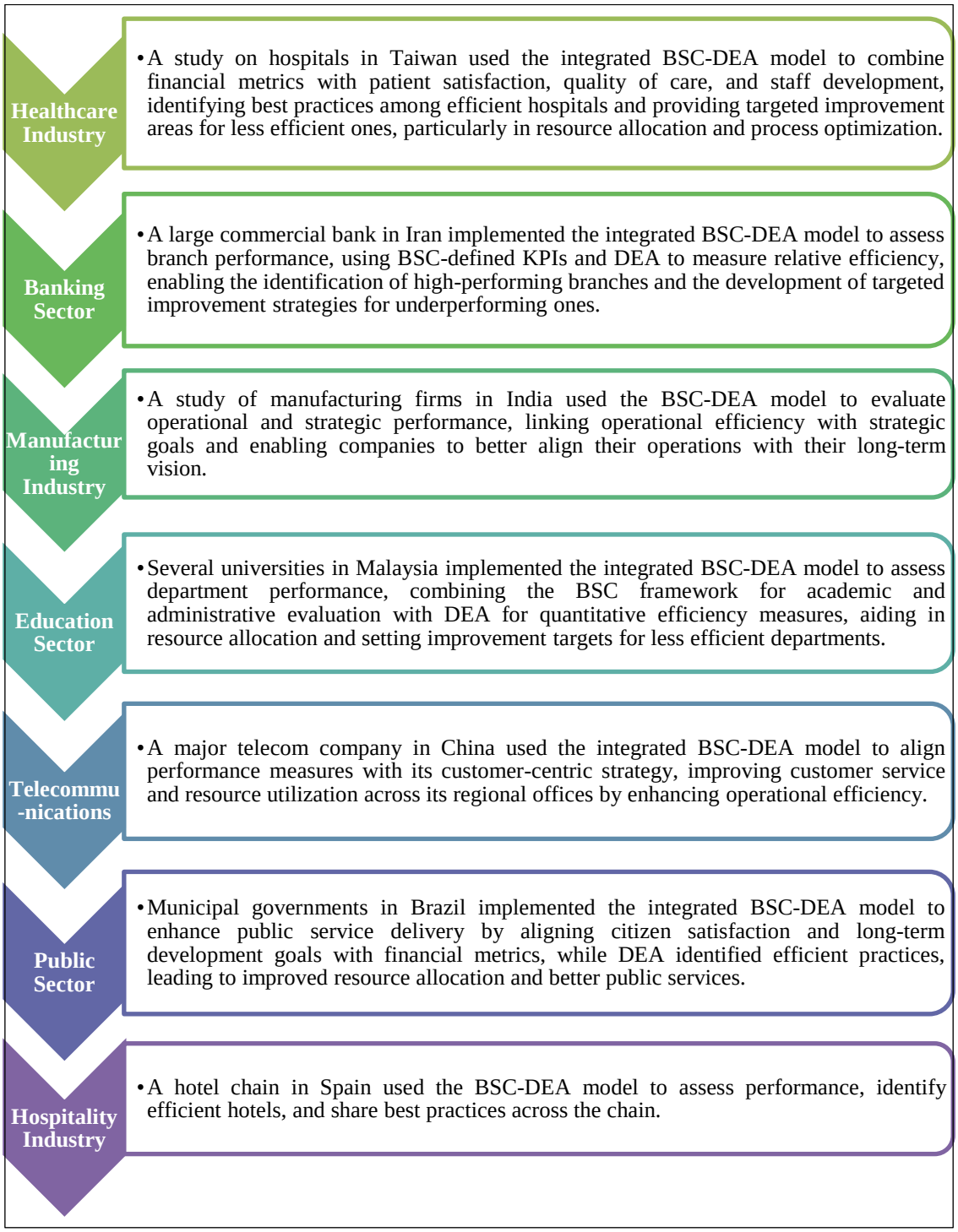

Figure 3 – Application of BSC-DEA across various industries (Tawse et al., 2023)

Several authors worldwide have attempted to combine BSC and DEA methods on both theoretical and abstract levels. These studies aim to leverage the strengths of both methodologies to enhance performance evaluation and strategic management. Below is a summary of key themes and findings from studies dedicated to integrating BSC and DEA (Table 1).

Table 1 – The summarisation of studies dedicated to the combination of BSC and DEA methods

Authors of the study	Content	Methods of analysis	The goal of integrating BSC and DEA	The applied approach to the integration of BSC and DEA
Rouse et al. (2002)	Airline Engineering Services Division	DEA, BSC Malmquist index, Pyramid of performance	Carry out regular performance measurements and determine the causes of deficiencies.	In the first phase, DEA is used to measure efficiency and productivity over time. In the second phase, a performance pyramid is compiled, including 4 BSC perspectives, in order to understand and act on the basis of DEA results.
Banker et al. (2004)	US telecommunications industry	BSC, DEA, Test statistics	Evaluate the trade-offs between different performance indicators.	Two DEA models are applied, and four performance indicators are considered as outputs. In one of these models, trade-offs between outputs are allowed; in the other, they are not. Several test statistics were performed in order to test the existence of trade-offs between performance indicators.
Eliat et al. (2006-2008)	Portfolio of research and development projects	DEA, BSC, "Branch-and-Bound" algorithm	Design and demonstrate a methodology for constructing and analysing effective and performance-balanced portfolios of R&D projects.	The proposed methodology consists of seven steps: Allocation of resources, Individual evaluation of the project, Project variability control, Generating portfolios, Using an accumulation function to determine inputs and outputs of competing portfolios, evaluation of alternative portfolios, and Sensitivity analysis.
				The methodology evaluates individual R&D projects according to the required characteristics in different life cycle phases.
Chen et al. (2007)	An industry engaged in the design and manufacture of semiconductor devices in Taiwan.	DEA, BSC	Evaluation of the performance of this industry	The first step is to select suitable indicators related to individual BSC perspectives. In the second step, DEA models were proposed based on selected indicators according to perspectives. The results of the models were compared.
Chen et al. (2008)	Banks in Taiwan	DEA, BSC, Wilcoxon	Determine how the selection of performance	The authors compare the results of four DEA models: the first model includes basic

Authors of the study	Content	Methods of analysis	The goal of integrating BSC and DEA	The applied approach to the integration of BSC and DEA
		Signed Ranks Test	indicators affects performance outcomes.	inputs and outputs, the second model includes BSC indicators, the third model includes BSC indicators with risk management, and the fourth model includes traditional financial indicators.
Min et al. (2008)	Luxury Korean hotels	DEA, BSC	Develop a new model to compare the efficiency of hotels.	The results obtained by means of DEA, including the basic inputs and outputs, are used as indicators of the efficiency of the financial perspective of the BSC. It considers four traditional BSC perspectives.
Chiang and Lin (2009)	Automotive companies and the US commercial banking sector	DEA, BSC, Factor analysis, Component analysis, Canonical correlation analysis	To evaluate performance in two various industries and test the interrelationships between the four BSC perspectives.	In the first phase, a statistical analysis is performed to test the hypothetical interrelationships between the four BSC perspectives. A DEA model with four input and four output variables is used in the second phase. Each outcome variable was calculated using one mean of the BSC indicators for each of the four perspectives.
Macedo (2009)	Bank branches in Brazil	DEA, BSC	Evaluate the performance of bank branches	A DEA model was created using six indicators based on six BSC perspectives. Indicators of the perspectives Strategy and Operations, Internal Processes and Organizational Behavior were chosen as inputs and indicators related to the perspective of Economic Results, Customer and Environment as outputs of the DEA model.
García-Valderrama at al. (2009)	Companies of the chemical and pharmaceutical industry in Spain	DEA, BSC, Pearson's correlation coefficient, Factor analysis	Investigate relationships between BSC perspectives using multiple methods	In the first phase, five different DEA models are established to capture hypothetical cause-effect relationships within the BSC. In the second phase, ratio correlations between the results of each DEA model are calculated, and factor analysis is performed to

Authors of the study	Content	Methods of analysis	The goal of integrating BSC and DEA	The applied approach to the integration of BSC and DEA
				obtain an interpretation of the correlation.
Asosheh et al. (2010)	IT projects	BSC, DEA	Assessment of IT projects	The proposed model for IT projects takes into account 5 perspectives - four original and perspectives of uncertainty.
Niknazar (2011)	IT investments	BSC, DEA	Assessment of investments in IT	The proposed methodology uses the BSC-DEA model to identify the impact of IT investments and the importance of IT-related activities on the efficiency of the enterprise. It also deals with the managerial results of efficiency evaluation using this model.
Shafiee et al.	Iranian food industry	BSC, DEA	Supply Chain Performance Evaluation	One of the most complicated decision-making problems for managers is the evaluation of supply chain performance, which involves various criteria. This model evaluates supply chain efficiency. The findings could be used in various evaluation processes in different industries.
Neda Vitezić, Antonija Petrlić (2019)	Public health services	BSC, DEA	Measuring the Efficiency and Effectiveness of Public Health Services	The proposed analytical-predictive model (APE) uses BSC combined with DEA to measure relative and technical efficiency as well as long-term effectiveness, and it contributes to the improvement of analysis, forecasting, and optimisation of public health institutions' activities.
Chaharlang et al. (2023)	Municipalities	BSC, DEA	Integrated System for Measuring Performance of Social Systems Using Uncontrollable Factors	The examined model evaluates the performance of the municipalities of Shahriar city using a combined method of BSC and DEA. The network model was investigated and analysed in two cases, i.e., when two areas of customer and social responsibilities are examined in the form of one area.

Generally, the approaches to integrating DEA and BSC methods worldwide can be divided into 5 categories (Figure 4).

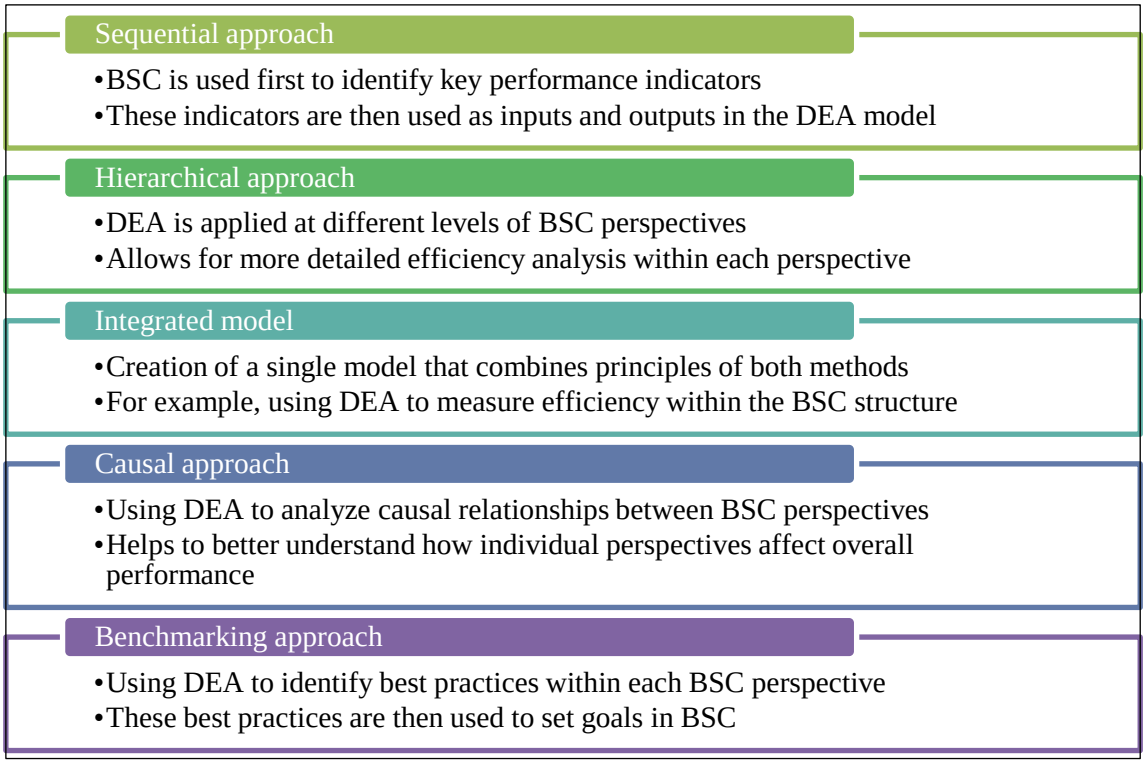

Figure 4 – Approaches to integrating DEA and BSC

Each of these approaches has its advantages and limitations. The choice of a specific approach often depends on the organisation's specific needs, data availability, and analysis objectives.

2 PROPOSAL FOR IMPLEMENTING THE BSC-DEA MODEL IN AN INDUSTRY 4.0 COMPANY

The implementation of the BSC-DEA model in an Industry 4.0 company offers a powerful approach to enhancing performance management. By integrating strategic and operational perspectives, the model provides a comprehensive framework for evaluating efficiency, aligning with strategic goals, and driving continuous improvement. With careful planning and execution, this approach can significantly contribute to achieving sustainable competitive advantages and long-term success.

A detailed explanation of the implementation process for the integrated BSC-DEA model is shown in Figure 5.

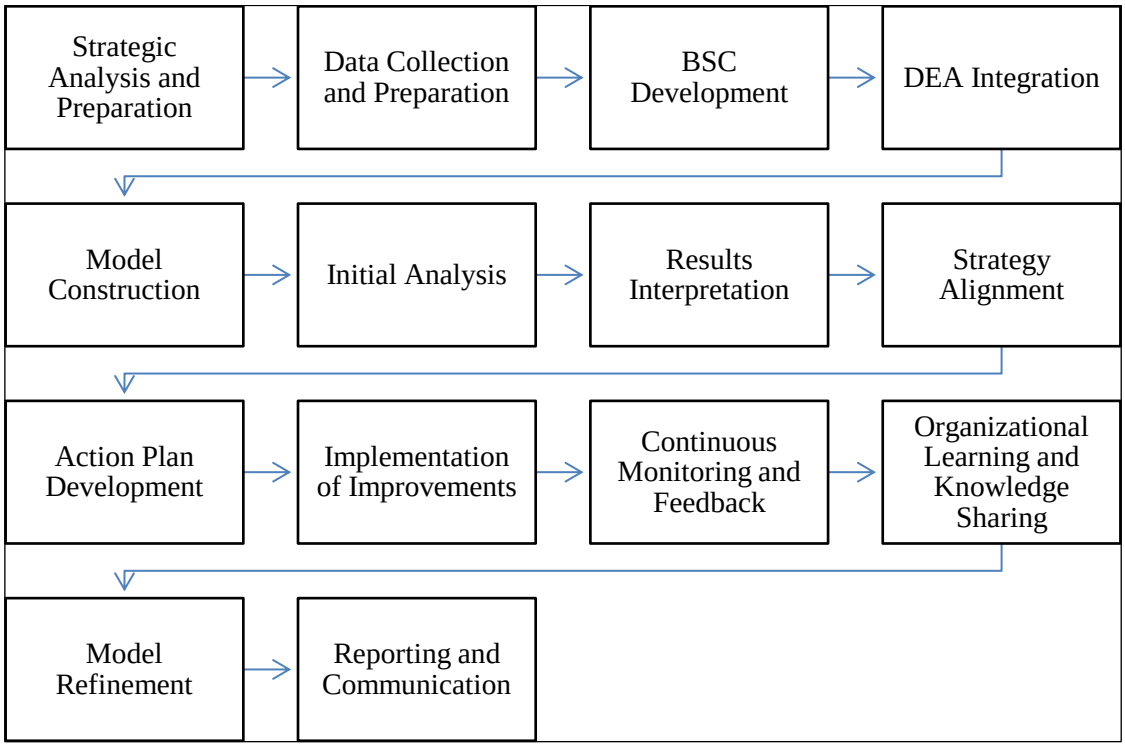

Figure 5 – Implementation process for the integrated BSC-DEA model in the company

The individual steps of the proposed process of implementing the integrated BSC-DEA model can be described in more detail as follows:

1. Strategic Analysis and Preparation define strategic objectives and identify key stakeholders' expectations.
2. BSC Development means the next steps (Frederico at al, 2021):
   - define 4th Generation BSC perspectives, including financial, customer, internal processes, learning and growth, as well as social and environmental impact, to ensure comprehensive performance tracking,
   - develop strategic objectives for each perspective,
   - create a strategy map linking objectives across perspectives,
   - establish key performance indicators (KPIs) for each objective - identify KPIs that are directly relevant to Industry 4.0 goals, such as operational efficiency, innovation, and technological integration.
   - set targets for each KPI.
3. DEA Integration requires the following steps (Braglia et al., 2022):
   - identify decision-making units (DMUs) within the company - focus on critical units, such as production, R&D, or quality control, where improvements will have the most significant impact on efficiency and innovation,
   - select relevant inputs and outputs based on the KPIs,

- assign weights to the inputs and outputs based on their strategic importance,
- determine the DEA model type based on organisation characteristics:
  - The CCR (Charnes–Cooper–Rhodes) DEA model is a model of constant returns to scale.
  - The BCC (Banker-Charnes-Cooper) DEA model is a model of variable returns of scale.

4. Data Collection and Preparation means gathering data for BSC KPIs and DEA inputs/outputs (Sutoova at al. 2018).
5. Model Construction involves the following steps:
   - develop the mathematical model integrating BSC and DEA,
   - program the model using appropriate software (e.g., R, MATLAB, specialised DEA software, Python programming language, or Excel for basic data handling and the Solver add-in for optimisation).
   - implement IoT devices, AI, and other digital tools to capture real-time data, allowing for dynamic KPI tracking across the BSC framework.
   - automation can be used to streamline data collection, feeding real-time information directly into the BSC-DEA model to support immediate insights and adjustments.
6. The initial analysis involves running the integrated model, calculating efficiency scores for each DMU, and identifying which units are efficient and which are inefficient.
7. Interpret results by analysing efficiency scores within Balanced Scorecard perspectives, identifying best practices from efficient units, and determining improvement targets for inefficient units.
8. Strategy Alignment means alignment of DEA results with BSC strategic objectives, adjusting strategies or targets as needed based on efficiency analysis.
9. Develop specific action plans for improvement, prioritising resource allocation and process enhancements based on the integrated analysis.
10. Implementation of Improvements involves the execution of action plans and monitoring of progress using both BSC and DEA metrics.
11. Continuous Monitoring and Feedback involves regularly updating data and rerunning the integrated model, assessing progress towards targets and efficiency improvements, and adjusting strategies, objectives, or metrics as needed. Use predictive analytics to forecast performance based on current trends and prescriptive analytics to suggest optimal strategies for improvement. This allows proactive management, helping to anticipate issues and optimise resources in line with DEA efficiency and BSC targets (Zgodavová et al., 2013).

12. Organisational Learning and Knowledge Sharing means disseminating insights and best practices throughout the organisation and conducting training sessions on the integrated model and its implications.
13. Model Refinement entails periodically reviewing and refining the integrated model by incorporating new metrics or adjusting existing ones as organisational needs evolve.
14. Reporting and Communication require developing comprehensive reports presenting BSC and DEA results and sharing findings and progress with stakeholders at all levels. The use of this feedback is to make continuous improvements to the system.

By following this implementation process, an Industry 4.0 company can successfully integrate the BSC-DEA model into its performance management system, enabling it to assess financial health, improve operational efficiency, and achieve strategic goals more effectively. This step requires a strong understanding of both BSC and DEA methodologies and proficiency in mathematical modelling and programming. It's often carried out by a team that includes strategists, data analysts, and operations researchers.

3 PROPOSAL FOR THE MATHEMATICAL REPRESENTATION OF THE INTEGRATED BSC-DEA MODEL

The BSC framework is a way to measure an Industry 4.0 company's performance and shows whether management is achieving the desired results. The BSC translates purpose, mission, and vision statements into objectives and performance measures that can be quantified and appraised. These measures, according to the latest approaches, include the following categories of performance (Management Tools and Trends 2023):

- Financial performance (revenue, earnings, return on capital, cash flow).
- Customer value performance (market share, customer satisfaction measures, customer loyalty).
- Internal business process performance (productivity rates, quality measures, timeliness).
- Innovation performance (percentage of revenue from new products, employee suggestions, rate of improvement index).
- Employee performance (morale, knowledge, turnover, use of best demonstrated practices).
- Environmental, social, and governance performance (greenhouse gas emissions, water consumption, employee diversity, health and safety incident rates, number of data breaches).

In the context of the integrated BSC-DEA model, the BSC serves as the foundation for defining inputs and outputs for the DEA analysis.

Let X_{ij} represent the value of the *j*–th indicator under the *i*-th perspective for a given DMU.

The DEA framework evaluates the relative efficiency of DMUs by solving a linear programming problem. Each DMU is engaged in a transformation process, where by using some inputs (resources), it tries to produce some outputs (goods or services).

DEA uses all the data available to construct a best practice empirical frontier, to which each inefficient DMU is compared. It is called the Production Possibility Frontier (PPF). It assumes that all inputs are used efficiently (Figure 6).

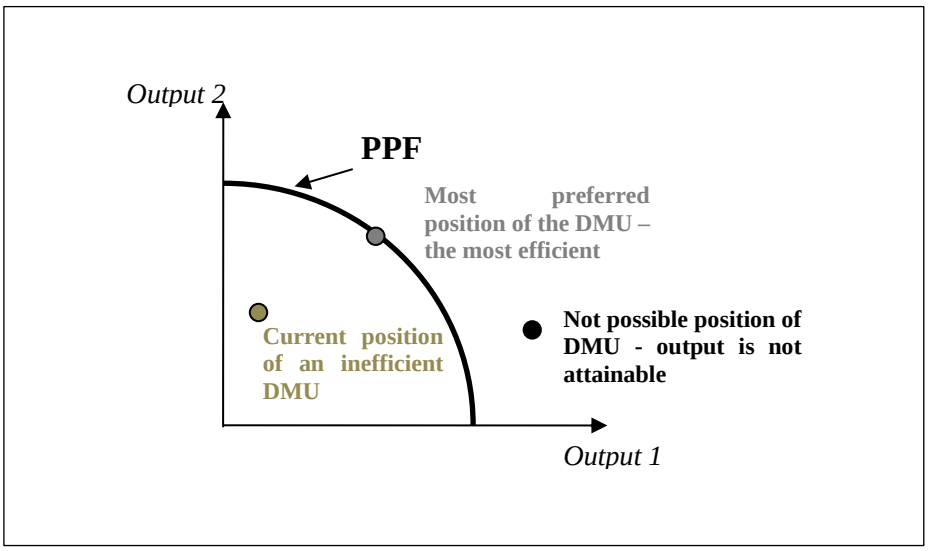

Figure 6 – Illustration of a possible location of the most preferred future position of the DMU (Kádárová et al., 2013)

DEA uses the production frontiers to assess relative efficiency. DEA forms efficient surfaces based on the units' inputs and outputs. If a DMU lies on the surface, it is efficient; otherwise, it is inefficient. One of the interesting features of DEA is that it allows each unit to identify a benchmarking group (a group of units that are following the same objectives and priorities but performing better) (Hassan et al., 2010).

The efficiency of each DMU is calculated as the ratio of total weighted outputs to the total weighted inputs.

The efficiency score ***(θ)*** for a given DMU ***k*** is formulated as:

θq = Weighted sum of Outputs/ Weighted sum of Inputs

$$Maximize\ \theta_k = \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}} \qquad (1)$$

Subject to:

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1 \qquad \forall\, j = 1,2,\dots,n$$

$$u_r v_i \geq 0$$

Where:

- X_{ik} is the *i-th* input of DMU *k*
- Y_{rk} is the *r-th* output of DMU *k*
- u_r and v_i are the weights assigned to the outputs and inputs *i*

In the integrated BSC-DEA model:

- Inputs and Outputs: The indicators from the BSC perspectives serve as inputs and outputs in the DEA model.
- Weight Restrictions: The BSC framework allows the incorporation of managerial preferences and strategic importance into the DEA model through weight restrictions. This can be done by imposing bounds on the weights (u_r ,v_i) to reflect the relative importance of different perspectives.

The integrated DEA model can be formulated as:

$$Maximize\ \theta_k = \frac{\sum_{p=1}^{P} \sum_{j=1}^{sp} u_{pj} Y_{pjk}}{\sum_{q=1}^{Q} \sum_{i=1}^{mg} v_{qi} X_{qik}} \qquad (2)$$

Subject to:

$$\frac{\sum_{p=1}^{P} \sum_{j=1}^{sp} u_{pj} Y_{pjl}}{\sum_{q=1}^{Q} \sum_{i=1}^{mg} v_{qi} X_{qil}} \leq 1 \qquad \forall\, l = 1,2,\dots,n$$

$$u_{pj} v_{qi} \geq 0$$

Where:

- *P* and *Q* denote the number of perspectives considered as outputs and inputs
- s_p and m_q represent the number of indicators under the *p-th* and *q-th* perspectives
- Y_{pjk} and X_{qik} represent the output and input values for the *j-th* indicator under the *p-th* perspective and the *i-th* indicator under the *q-th* perspective for DMU *k*

Efficiency Score Interpretation: The efficiency score $\boldsymbol{\theta_k}$ reflects how well a DMU performs relative to its peers, considering the multiple perspectives defined by the BSC. A score of 1 indicates that the DMU is on the efficiency frontier, meaning it is one of the best-performing units, while a score less than 1 indicates relative inefficiency.

Implementing the BSC-DEA Model in Excel: The Excel Solver add-in is activated for solving DEA models, which is adequate for DEA analysis involving a limited number (up to 100) of inputs and outputs with several constraints. Automatic execution of Solver can be facilitated by recording a macro. The macro used for DEA analysis has been customised through the Microsoft Visual Basic for Applications (VBA) editor, available on the "Developer" tab in the Excel ribbon.

Upon activation and execution of the predefined macro and after setting the DEA model parameters and input values, the model recalculates virtual inputs and outputs and determines the efficiency of the assessed DMUs.

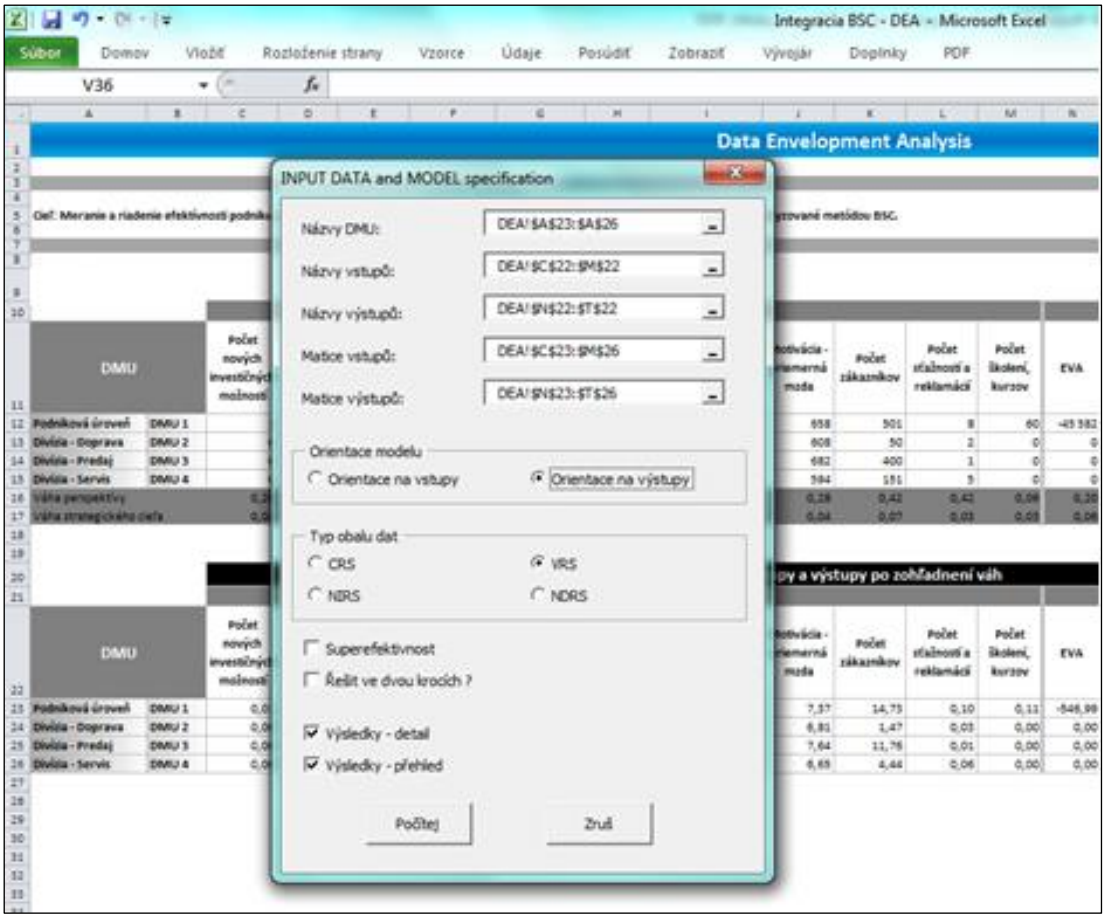

Figure 7 – Calculation of the efficiency of selected DMUs by Excel Solver

After running Solver for each DMU, we will get the optimal weights and efficiency scores. Using Excel and Solver, a basic BSC-DEA model can be implemented to evaluate different decision-making units' financial health and efficiency. This method provides a simple yet powerful way to apply the principles of the integrated model without needing to write complex code. The flexibility of Excel also allows us to update data, adjust constraints, and visualise results easily.

4 CONCLUSION

The integrated BSC-DEA approach allows Industry 4.0 companies to identify inefficiencies in their processes and focus on areas that require improvement. Implementing a BSC-DEA model in an Industry 4.0 company allows for a structured, data-driven approach to performance management. The company can achieve operational excellence, enhance innovation, and secure a sustainable competitive advantage by aligning strategic objectives with real-time data insights. This leads to continuous enhancement of the quality of products and services. By providing a comprehensive view of organisational performance, the model helps uncover shortcomings that might otherwise go unnoticed, resulting in higher quality across all aspects of the business. The model fosters innovation by enabling more effective resource allocation and identifying best practices. Companies can better understand where innovations yield the most value by measuring the efficiency of different organisational units. This frees up resources for further research and development, allowing companies to implement innovative solutions more quickly. The integration of BSC and DEA enhances strategic management and company performance, leading to improved financial health and long-term prosperity. The model helps companies allocate resources efficiently, reducing costs and increasing profitability. Additionally, supporting quality and innovation boosts the competitiveness of companies in the market, positively impacting their sustainable growth and prosperity.

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CONFLICTS OF INTEREST

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