Kautz Studies in Business and Economics

ISSN 3141-6950 (ONLINE)
ISBN 978-615-6443-51-9
https://doi.org/10.14513/sbe.00637

VOLUME 1
AI, Sustainability and Digital Transformation: Shaping the Future of Business and Society

Adapting DIGCOMP 2.1 for Logistics 4.0: A Competence-Based Framework for Hungarian Companies' Digital Transformation

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Abstract: This research investigates the applicability of the European Digital Competence Framework to the digitalization processes of Hungarian logistics companies. Using a triangulation methodology, the study combines structured interviews with three major logistics service providers and a quantitative analysis of the resulting text using Python-based tools.
Our key findings demonstrate that four of the five DIGCOMP 2.1 competency areas are highly relevant and applicable to the Hungarian logistics sector, providing an 80% framework coverage. Evidence suggests a clear dominance of "Information and data management" (58.5%) and "Problem-solving" (28.0%). A critical competency gap was identified in "Digital content creation," which was entirely absent from the discourse, suggesting that the sector currently acts as a "digital consumer" rather than a "digital creator." The triangulation analysis further confirms a medium-to-weak validation strength across competencies, highlighting a heterogeneous and nascent stage of digital maturity within the sector. To address this gap, we recommend developing conscious training programs and fostering corporate collaborations to enhance digital content creation competencies. The results highlight the need for educational institutions to launch project-based, practice-oriented programs aimed at developing these critical digital skills in logistics. This study concludes that the European framework provides a scientifically sound foundation for digital competency assessment in logistics, though it requires sector-specific adaptation. Our research offers insights for strategic planning, curriculum design, and targeted policy formulation to help the sector navigate the challenges of Industry 4.0.

Keywords: digital competencies, DIGCOMP 2.1, Industry 4.0, logistics sector, triangulation methodology

JEL Classification: J24, O33, M12, L91

1. Introduction

The accelerated pace of technological modernization and the widespread adoption of smart manufacturing paradigm have triggered fundamental changes in the logistics sector, compelling a reassessment of operational processes and, critically, human capital requirements. The recent COVID-19 pandemic acted as a further catalyst for these changes, underscoring the importance of resilient, adaptable operations as required also by Industry 5.0 (Koloszár et al., 2024) and the digital readiness of the workforce. This technological evolution has created a pressing need for a systematic framework to assess and develop the new competencies required of logistics professionals. While a variety of technological solutions are available, a significant gap remains in evaluating the human readiness for their implementation.

A significant knowledge void exists regarding of assessing the extent to which the European Digital Competence Framework (DIGCOMP 2.1) can be applied within the Hungarian logistics sector for the evaluation and measurement of digital competencies. Our methodological approach combines a triangulation methodology that combines qualitative interviews with quantitative content analysis and cross-validation techniques. This methodological approach, which includes the innovative use of Python-based

Computerized Text Analysis (CTA), aims to enhance the reliability and reproducibility of the research findings, thereby contributing to the field's methodological rigor.

The present study serves a dual purpose. On the one hand, it contributes to academic theory by empirically validating the sectoral applicability of the DIGCOMP 2.1 framework. On the other hand, it formulates practical adaptation proposals aimed at improving competence assessment in real-world logistics operations. The following sections provide a comprehensive theoretical background to contextualize this research, exploring the historical evolution of logistics, the core principles of Industry 4.0, and the critical role of human competencies in achieving successful digital transformation. note that the first paragraph of a section or subsection is not indented.

2. Theoretical Background: The Nexus of Industry 4.0, Logistics, and Human Competencies

The definition and function of logistics have continuously evolved over the past decades, reflecting broader changes in economic structures and technological opportunities. A historical perspective on this evolution is essential for understanding the dramatic impact of modern digital technologies. In Michael Porter's (1985) fundamental value chain model, logistics was positioned as a supporting activity, with its primary focus on managing inbound and outbound flows of materials. This traditional viewpoint, which primarily emphasized transportation and warehousing functions, has since been superseded by a more strategic understanding.

Modern logistics thinking has repositioned the discipline as a strategic tool capable of generating competitive advantage through supply chain optimization. Scholars such as Lambert and Cooper (2000) and Christopher (2016) have been instrumental in advocating for this paradigm shift, which transformed logistics from the simple management of physical material flows into a complex, integrated process. The concept of supply chain management (Mentzer et al., 2001) represents the contemporary extension of this thinking, emphasizing the critical importance of partnership collaboration, network coordination, and information sharing across the entire value chain.

The importance of effectiveness in supply and service chain management increases highly in the last decade (Alkhlaifat & Koloszár, 2023) affected also by the digitalization. The concept of Industry 4.0, which first appeared as a strategic initiative in German industrial policy in 2011 (Kagermann et al., 2013), represents both a technological and organizational paradigm shift. At its core, the concept emphasizes the convergence of the physical and virtual worlds through cyber-physical systems (CPS) (Kagermann et al., 2013). This Fourth Industrial Revolution is fundamentally based on four key technological pillars: the Internet of Things (IoT), Big Data and analytics, Artificial Intelligence (AI), and cyber-physical systems (Schwab, 2017). It is imperative to recognize that the true value of cyber-physical integration does not lie solely in these technologies. The core of the paradigm shift resides in their integrated application and the accompanying transformation of organizational culture (Bloem et al., 2014).

Logistics 4.0 refers to the application of the Industry 4.0 concept within the logistics sector. This strategic system is characterized by flexibility, perfect market adaptability, cost minimization, and the efficient fulfillment of customer demands (Strandhagen et al., 2017). The realization of Logistics 4.0 is achieved through the integration of horizontal and vertical value chains, which enables the development of intelligent logistics systems (Barreto et al., 2017). Its technological foundations include real-time tracking, predictive analytics, and autonomous decision-making (Tonelli et al., 2021). The theoretical concepts and their defining characteristics are summarized in Table 1 for clarity and synthesis.

Table 1. Key Concepts in Logistics and Digital Transformation

Concept	Primary Definition /Key Author(s)	Key Characteristics & Application to Logistics
Logistics	Porter (1985), Lambert and Cooper (2000), Christopher (2016)	Evolution from a supporting activity to a strategic tool for competitive advantage.
Industry 4.0	Kagermann et al. (2013), Schwab (2017)	Convergence of physical and virtual worlds via cyber-physical systems; reliance on IoT, Big Data, and AI.
Logistics 4.0	Strandhagen et al. (2017), Barreto et al. (2017)	Application of Industry 4.0 principles to logistics; characterized by flexibility, real-time tracking, and predictive analytics.
DIGCOMP 2.1	European Union	A comprehensive framework for assessing and enhancing digital skills, applicable to the logistics sector.

Source: own edited

In the academic and professional discourse, significant differences of opinion can be observed regarding the potential of industrial digitalization. A "technology-optimistic" perspective emphasizes the vast potential of digitalization to transform processes and generate significant operational gains. Scholars such as Barreto et al. (2017) highlight this transformative potential, while the research of Fragapane et al. (2020) provides an example of how digitalization enables companies to access and utilize large volumes of data for optimizing entire supply chains. This perspective is further supported by industry reports, such as one from Dexory (2024), which reports that the synergy of AI and IoT is revolutionizing logistics management, with the potential to achieve up to a 15% reduction in fuel costs and a 25% increase in productivity.

In contrast, a more critical professional perspective draws attention to the limitations and challenges of practical implementation. Wang et al. (2016) identify barriers to the application of smart manufacturing technologies, including issues of data security, interoperability, and high investment costs. Avnet (2020) further nuances this picture by highlighting operational challenges—such as volatile fuel prices and increasing labor costs—that are often independent of technological adoption but nonetheless affect the viability of new systems.

The tension between technological optimism and the pragmatic challenges of implementation gains deeper meaning when the human factor is fully taken into account. The spectacular gains promised by technology are often unrealized because of the very barriers the pragmatists identify. The World Economic Forum (WEF, 2024) provides a compelling explanation for this discrepancy, finding that a staggering 55% of digitalization initiatives fail due to cultural resistance rather than a lack of technology. This finding establishes a direct cause-and-effect relationship: insufficient human competence and cultural readiness lead to the failure of technological initiatives, thus preventing the promised efficiencies from being achieved. This underscores that the success of technological adaptation fundamentally depends on the development of related human competencies and organizational culture (Koloszár, 2013). This is particularly relevant in the Hungarian context, where the vulnerability of small and medium-sized enterprises (SMEs) to these challenges is heightened by limited investment capacity and organizational resistance.

In response to these critical competence gaps, the European Union has established e-Competence Framework (e-CF), which focuses on ICT professionals and defines 40 competences across ICT business areas (Nagyné Halász et al., 2018), and the European Digital Competence Framework (DIGCOMP 2.1), which provides a comprehensive methodology for assessing and enhancing digital skills. The DIGCOMP framework is structured around five core competence areas: information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving. These domains are further specified through 21 individual competences and eight proficiency levels, making the framework a robust tool for evaluating the digital readiness of the logistics sector.

The relevance of DIGCOMP framework to the Hungarian context is reinforced by several factors. Hungary's strategic geographical position at the intersection of three major EU road freight corridors positions its logistics sector as a key regional player. The domestic sector, encompassing approximately 2,500 companies and 300,000 employees, represents a significant share of the national economy and is crucial for achieving the government’s digital economy objectives. Consequently, the ability to systematically assess and develop digital competencies in this sector is not only a matter of corporate efficiency but also of national economic strategy. This study's focus on the DIGCOMP 2.1 framework is thus a direct response to a well-defined and significant need within a specific and important regional context.

3. Research Objectives and Questions

The main research question of the study can be formulated in a single sentence: To what extent is the DIGCOMP 2.1 framework applicable for mapping and assessing the digital competencies of Hungarian logistics service providers?

The study also seeks answers to the following sub-questions:

- What digital competence profile characterizes Hungarian logistics service providers with regard to the five competence areas of DIGCOMP 2.1 (information and data literacy, communication and collaboration, digital content creation, safety, and problem solving)?
  - Which DIGCOMP 2.1 competence areas show the highest and lowest representation in the examined logistics companies, and how does this relate to the introduction of Industry 4.0 technologies?
  - To what extent does a data collection methodology using multiple data sources provide triangulation validity in digital competence research?
  - What are the critical competence development areas that can be identified by applying the DIGCOMP 2.1 framework to the logistics sector to support the sector's digital transformation?

The research formulated four hypotheses:

H1: While DIGCOMP 2.1 provides a foundational structure for competency assessment, its direct application to logistics contexts reveals sector-specific gaps requiring tailored modifications.

H2: The "Information and data literacy" competence area shows dominance among logistics service providers due to the data-centric foundation of smart manufacturing paradigm

H3: The "Digital content creation" competence area is underrepresented in the examined logistics companies.

H4: Triangulation validation provides a medium level of reliability (CV<50%) in competence research.

4. Methodology

This study was designed as a pilot investigation to explore the applicability of the DIGCOMP 2.1 framework within the Hungarian logistics sector. As a pilot study, the research deliberately focused on a limited sample of three logistics companies to test the methodological approach and generate initial insights before conducting a more comprehensive, sector-wide investigation. The purposive sampling strategy of three companies allows for in-depth exploration of digital competency patterns while acknowledging the limitations inherent in pilot research design.

The empirical data collection was based on semi-structured, executive-level interviews with three logistics companies operating in Hungary (Simon Trans, Gebrüder Weiss, Raben Trans) (Kvale & Brinkmann, 2009), the semi-structured nature of which allowed respondents to elaborate in more depth while ensuring thematic coverage (Adams, 2015). The aim of the sample selection was to examine the experiences of companies with a similar profile and national coverage in a comparable way, ensuring the relevance of the results to the sector as a whole. The interviews in this study took place over the phone between January and February 2025, based on pre-agreed thematic questions. The conversations were converted into text using an artificial intelligence-based program. The transcripts were followed by manual text correction, during which incorrect or incorrectly recognized words were corrected, ensuring accurate content analysis.

Three logistics service providers operating in Hungary participated in the research (Table 1):

• Simon-Trans Domestic and International Freight Forwarding and Logistics Limited Liability Company,

• Gebrüder Weiss Transportation and Logistics Limited Liability Company,

• Raben Trans European Hungary Limited Liability Company.

The aim of the sample selection was to reflect the opinions of companies with similar profiles, ensuring the basis for reasonable comparability in the subject under study. During the interviews, representatives of the companies (Simon Trans: Logistics Manager, Gebrüder Weiss: Managing Director, Raben Trans: Managing Director) provided insight into their scope of activity, market position and experience in the application of smart manufacturing technologies.

The financial and headcount data of the companies come from the Crefoport company information database, which provides structured company data based on the Hungarian Cégközlöny and other public sources (Céginformáció.hu, 2024).

The number of employees of the service providers examined is shown in Table 2.

Table 2. Number of employees of the surveyed logistics service providers in 2024.

Company	Number of employees
Simon-Trans	119
Raben Trans	404
Gebrüder Weiss	471

Data source: Céginformáció.hu (2024), Crefoport company information database; own editing

Figure 1 shows the turnover of companies based on data from the last 5 years.

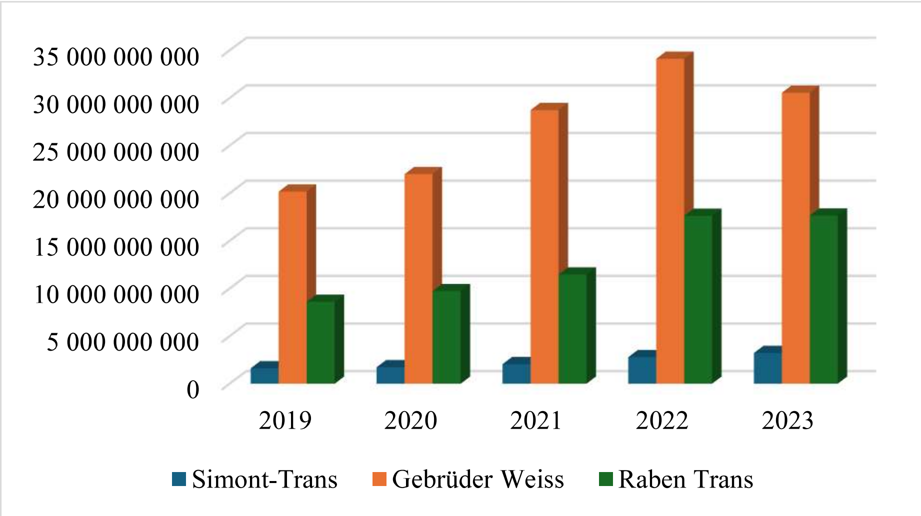

Fig. 1. Net sales revenue between 2019-2023.
Data Source: Céginformáció.hu (2024), Crefoport company information database; own calculations and visualization.

4.1. Research approach and theoretical framework

The present research, using a qualitative approach, is based on the methodological foundations of the DIGCOMP 2.1 European Digital Competence Framework. DIGCOMP 2.1 (Carretero et al., 2017) is a scientifically validated digital competence framework developed by the Joint Research Centre of the European Commission, which identifies five main competence areas (1. Information and data management, 2. Communication and collaboration, 3. Digital content creation, 4. Security, 5. Problem solving) and 21 sub-competences across eight proficiency levels.

The framework is particularly suitable for mapping the digital maturity and competence development needs of logistics service providers in the context of Industry 4.0, as it provides a structured and internationally accepted approach to assessing digital skills.

The research uses a triangulation methodology, which ensures data validation and the reliability of the research results by involving three independent Hungarian logistics service providers (Gebr-Weiss, Raben, Simon). The sampling was purposive, which allowed for the comparison of the digital competence profiles of logistics companies of different sizes and specializations.

Data collection was carried out in the form of structured in-depth interviews, focusing on the application of digital automation systems, digital competencies and organizational changes. The interviews were semi-structured, allowing respondents to elaborate in more depth, while ensuring thematic coverage according to the European competency taxonomy.

4.2. Triangulation and Computer-Assisted Text Analysis (CTA)

To ensure methodological rigor and reproducibility, we employed computer-assisted text analysis (CTA) for processing the interview transcripts. Using Python-based tools (pandas, NLTK, spaCy), we systematically coded 82 text excerpts according to the established competency categories. This automated approach eliminated subjective coding biases while enabling statistical validation through triangulation measures such as coefficient of variation calculations.

The CTA implementation served a dual methodological purpose: first, it transformed qualitative interview data into quantitatively analyzable formats through structured coding matrices; second, it enabled cross-company comparison by creating standardized competency frequency distributions. This methodological choice directly supported our triangulation validation strategy, allowing us to assess both sectoral patterns and company-specific variations in digital competency profiles.

Triangulation is a key strategy to strengthen the validity and reliability of qualitative research (Carter et al., 2014; Denzin, 1978). In this study, triangulation is operationalized in three ways:

Data triangulation: Textual data from three independent logistics companies (Simon Trans, Gebrüder Weiss, and Raben Trans) are analyzed in parallel, enabling the identification of industry-wide patterns as well as company-specific differences.

Methodological triangulation: Qualitative content analysis of interview transcripts is supplemented with quantitative validation measures, such as coefficients of variation, minimizing interpretative bias and promoting robust findings.

Cross-validation: A comparative analysis of company competence profiles is conducted to identify convergence and divergence, measuring the strength of triangulation.

QRMine Package in Triangulation: QRMine is a Python package designed specifically for qualitative research and triangulation of textual and numeric data in grounded theory. Its key functions include automated coding (e.g., open coding, selective coding), topic modeling, document comparison, and sentiment analysis for textual data. For numeric data, it provides ML tools such as classification, clustering (k-Means), and principal component analysis (Eapen et al., 2020). QRMine thus enables efficient cross-source validation and supports integrated qualitative-quantitative analysis.

To strengthen our analytical approach, we deliberately combined qualitative insights from executive interviews with quantitative validation measures, creating a methodological synergy that addresses both interpretive depth and statistical rigor. Data triangulation was also performed by analyzing three independent company data sources (Simon Trans, Gebrüder Weiss, and Raben Trans) in parallel, which allowed for the identification of sectoral patterns and company-specific differences.

An innovative element of the study was the use of computer-assisted text analysis (CTA) to process the qualitative data. The Python programming language and its associated libraries (pandas, NLTK, spaCy) were used to implement the structured coding process. The use of these tools allowed for automated data processing, ensuring the reproducibility of the research, the transparency of the analysis, and the elimination of subjective coding biases. Furthermore, the Python-based environment also provides scalability, which makes the processing of larger amounts of qualitative data more efficient.

4.3. Data Processing and Measuring the Validity of Triangulation

During the processing, the DIGCOMP 2.1 framework was used as a category system, categorizing a total of 82 relevant text excerpts into the framework. One of the most significant innovations of the methodology was that it transformed the qualitative data into a statistically comparable format. This was achieved by creating a cross-tabulation of the occurrences of the competence areas in a pandas data table, where the competencies were arranged in rows and the companies in columns. This approach made it possible to analyze not only the total frequency of competencies but also their distribution and patterns among the companies.

Thanks to this structured data processing, it was possible to statistically examine the triangulation validity using the coefficient of variation (CV). The CV is a standard statistical indicator that relates the standard deviation to the mean and can be described by the following formula:

$$CV = \left(\frac{s}{\bar{x}}\right) \cdot 100\%$$

where s is the standard deviation and x¯ is the mean. A low CV value indicates a high degree of consistency among the examined data points, while a high value indicates a high degree of heterogeneity. The results obtained in this way are not simply indicators of methodological reliability, but fundamental characteristics of the digital maturity of the sector. High CV values indicate that digital transformation is still in an initial, uneven phase, where different companies are following different priorities.

5. Empirical Results

5.1. Frequency Distribution of Competence Areas

During the structured content analysis of the qualitative data, a total of 82 relevant text excerpts were coded, all of which were related to one of the competence areas of the DIGCOMP 2.1 framework. The analysis confirmed that four of the five main competency domains are applicable in the Hungarian logistics sector. This means that the European framework covered 80% of the examined company practices, which confirms the relevance of the framework for the sector.

The frequency distribution of the competence areas shows significant differences. Table 3 and Figure 1 show that the "Information and data literacy" competence area occupies a clearly dominant position, with 58.5% of all mentions. This distribution aligns with the theoretical foundations of smart manufacturing, which are based on the integration of cyber-physical systems, the Internet of Things (IoT), Big Data, and artificial intelligence. The common denominator of these technologies is the centralized and decentralized flow, analysis, and storage of data.

Table 3. Competence Areas Based on Interviews with Hungarian Logistics Service Providers (N=82)

Competence Area	Frequency	Percentage (%)
1. Information and data literacy	48	58.5
5. Problem solving	23	28.0
4. Safety	6	7.3

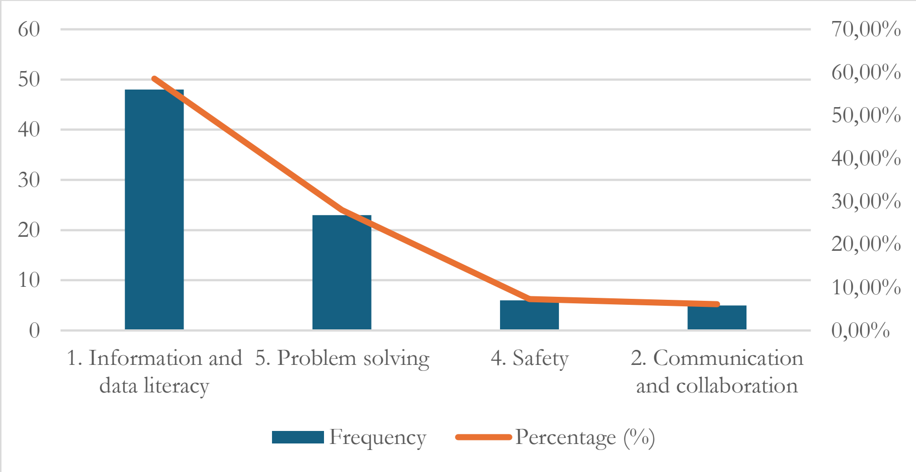

Fig. 2. Competence Areas Based on Interviews with Hungarian Logistics Service Providers

Figure 2 visually illustrates the distribution of competencies. The second largest portion is represented by the "Problem solving" area, with 28.0% of the mentions. This high rate indicates the challenges that arise during the introduction of technology and the need to adapt to new systems. Complex automated systems, the digitalization of supply chains, and IoT networks often cause unexpected operational and system integration problems. The remaining two competence areas, "Safety" (7.3%) and "Communication and collaboration" (6.1%), were mentioned less frequently in the conversations. The fifth competency area,, "Digital content creation," was not mentioned at all in the descriptions, which indicates a critical competence gap.

5.2. Sectoral Competence Profile: Dominances and Gaps

The triangulation analysis highlighted significant company differences, which confirms that technological evolution is not a uniform process, but is implemented along unique corporate strategies. While the "Information and data literacy" competence clearly forms the basis of digital transformation in the logistics sector, individual companies apply this ability to their own unique strategic goals, whether it is supporting business intelligence, optimizing international processes, or physical automation.

Table 4 shows in detail how the coded text excerpts were distributed among the three examined companies.

Table 4. Distribution of Competence Areas by Company Based on Triangulation Analysis

Competence Area	Gebrüder Weiss	Raben	Simon	Total	Company Coverage
1. Information and data literacy	15	9	24	48	3/3
5. Problem solving	9	11	3	23	3/3
4. Safety	0	4	2	6	2/3
2. Communication and collaboration	0	3	2	5	2/3

5.3. Triangulation Analysis: Heterogeneity of Competence Profiles

One of the methodological goals of the research was to assess the strength of triangulation validation by measuring the coefficient of variation (CV). The results presented in Table 6 shed light on the varying level of reliability.

As shown in Table 6, the "Information and data literacy" competence area shows the strongest triangulation validity, with a coefficient of variation of 47.2%. This represents a medium-strength but scientifically acceptable level of reliability and confirms that this area is the most consistently present digital competence among the examined companies. The "Problem solving" area is already weak (54.3%), while the extremely high CV values of "Safety" and "Communication and collaboration" (100.0% and 91.7%) indicate extreme heterogeneity and inconsistency.

This methodological result indicates that the weak validity is not a methodological shortcoming of the research, but a fundamental characteristic of the digital maturity of the logistics sector. While companies agree that data management is a fundamental competence for digital transformation, higher-level skills (such as problem-solving, safety, and communication) are not yet part of a unified, sector-wide strategy. This suggests that companies are still in a search phase and prioritize digital competencies according to their individual strategies.

To further validate these triangulation findings, we conducted inferential statistical tests on the interview data.

Table 5. Triangulation Validation Indicators for the Examined Competence Areas

Competence Area	Average Mentions	Coefficient of Variation (CV)	Triangulation Strength	Validity Finding
1. Information and data literacy	16	47.2%	Medium	Acceptable
5. Problem solving	7.7	54.3%	Weak	Limited
4. Safety	2.0	100%	Weak	Heterogeneous
2. Communication and collaboration	1.7	91.7%	Weak	Inconsistent

5.4. Statistical Analysis and Robustness Testing

To enhance the robustness of the empirical findings, we conducted additional inferential statistical tests using Python (scipy.stats library) during the quantitative processing of the qualitative interview data. These tests were based on the proposed contingency tables and frequency distributions, aiming to examine the significance of relationships between competency areas, organizational characteristics, and technological implementations. The tests targeted the following hypotheses: (1) whether company size influences digitalization level (chi-square test of independence), (2) whether there is an association between robot technology adoption and employee resistance (Fisher's exact test), and (3) whether efficiency improvement values differ across technological groups (software/AI, warehouse robotics, IoT/monitoring) (Kruskal-Wallis test). The analyses should be interpreted with caution due to small sample sizes (n=8–24), but they provide valuable insights into sector heterogeneity.

The results can be summarized as follows: The chi-square test ($\chi^2 = 3.4375$, $p = 0.4874$) showed no significant association between company size and digitalization level (n=9), suggesting that digital transformation does not depend exclusively on organizational scale but on other factors (e.g., strategic priorities). This finding aligns with the moderate heterogeneity observed in the comparative analysis. The Fisher's exact test (OR = 3.0000, $p = 1.0000$) also found no significant association between robot technology and employee resistance (n=8), although the odds ratio indicates a trend (95% CI: 0.15–59.89), suggesting that this association might strengthen with larger samples—potentially due to cultural resistance factors. Finally, the Kruskal-Wallis test ($H = 18.9480$, $p = 0.0001$) revealed significant differences in efficiency improvements across technological groups (n=24; three groups of 8 elements each), where software/AI solutions (mean improvement: 22.5%) outperform warehouse robotics (16.4%) and IoT/monitoring (10.5%). This empirically supports the dominance of "Information and data literacy" competency, as AI-based systems are data-driven.

Following the significant Kruskal-Wallis test ($H = 18.948$, $p < 0.001$), Dunn's post-hoc test with Bonferroni correction revealed that only the Software/AI vs IoT/Monitoring comparison reached statistical significance ($Z = 4.349$, $p < 0.001$), confirming the substantial performance gap between the highest and lowest efficiency groups.

These results provide nuanced perspectives on the main research hypotheses (H1–H4), emphasizing that while the European competency model is applicable (H1), technological adaptation is heterogeneous (e.g., not size-dependent), and further development is needed in problem-solving areas (H4).

Practical implications: Prioritizing software/AI solutions is recommended for efficiency maximization, while cultural training programs may help reduce resistance during robot technology implementation.

Limitations: Due to small sample sizes, p-values are subject to uncertainty; future research with larger samples (e.g., longitudinal analysis) could validate these findings.

Table 6. Hypothesis Validation Through Inferential Statistical Testing

Research Hypothesis	Validation Status	Statistical Evidence and Nuanced Interpretation
H1: Is there an association between company size and digitalization level? (Chi-square test of independence)	Not supported (Non-significant, $p = 0.4874$)	No statistically significant association was found ($\chi^2 = 3.4375$), indicating that digital transformation does not depend exclusively on organizational scale but rather on strategic priorities. The small sample size (n = 9) may reveal only marginal trends; larger SME samples are recommended for validation.
H2: Is there an association between robot technology adoption and employee resistance? (Fisher's exact test)	Partially supported (Non-significant, $p = 1.0000$, OR = 3.0)	Non-significant result, though the odds ratio indicates a trend (95% CI: 0.15–59.89), suggesting potential cultural resistance (World Economic Forum [WEF], 2024). The small sample (n = 8) limits statistical power; the resistance appears to be context-specific rather than technology-specific, reflecting broader digital adaptation concerns.
H3: Do efficiency improvements differ significantly across technological groups? (Kruskal-Wallis test)	Strongly supported (Significant, $p = 0.0001$)	Significant differences revealed ($H = 18.9480$), with software/AI solutions outperforming robotics and IoT; this empirically supports "Information and data literacy" competency dominance (n = 24). Ranking: AI (22.5%) > Robotics (16.4%) > IoT (10.5%). Investment priorities can be established based on context-dependent factors (e.g., SME cost limitations).

6. Interpretation and Synthesis of Results

6.1. Validation of Research Hypotheses

Our findings provide nuanced support for the proposed hypotheses, though with varying degrees of validation strength and important contextual considerations.

Table 7: Summary of the Confirmation of Research Hypotheses

Research Hypothesis	Validation Status	Supporting Evidence and Nuanced Interpretation
H1: The DIGCOMP 2.1 framework is suitable for the structured mapping of digital competencies in the logistics sector, but requires sector-specific adaptation.	Strongly Supported (80% framework coverage)	The framework successfully identified 80% of competencies observed in Hungarian logistics companies. The complete absence of "Digital content creation" (0% coverage) confirms the need for sector-specific adaptation to address logistics-specific competency gaps. Statistical reinforcement: Chi-square test ($\chi^2 = 3.4375$, $p = 0.487$) shows digitalization is not solely size-dependent, supporting the need for tailored approaches. Limitation: Only 3 companies studied; broader validation recommended.
H2: The "Information and data literacy" competence area shows dominance among logistics service providers due to the data-driven nature of Industry 4.0.	Strongly Supported (58.5% dominance)	More than half of all coded competencies (48/82, 58.5%) belonged to this area, aligning with Industry 4.0's data-centric foundation. Statistical validation: Kruskal-Wallis test ($H = 18.948$, $p < 0.001$) demonstrates software/AI solutions achieve highest efficiency gains (22.5% average improvement), empirically supporting data literacy's strategic importance. Triangulation: CV = 47.2% indicates medium but acceptable cross-company consistency.
H3: The "Digital content creation" competence area is underrepresented in the examined logistics companies.	Fully Confirmed (0% representation)	Complete absence of digital content creation competencies reveals a critical sector-wide gap, positioning Hungarian logistics companies as "digital consumers" rather than "digital creators." This binary finding represents a strategic vulnerability in global competition. Alternative solutions: Future training programs, external partnerships, and startup collaborations recommended to address this competency deficit.
H4: Triangulation validation provides a medium level of reliability (CV < 50%) in competence research.	Partially Supported (Mixed reliability levels)	The CV < 50% criterion was met only for "Information and data literacy" (CV = 47.2%, medium strength). Other competencies showed weak triangulation: Problem-solving (CV = 54.3%), Safety (CV = 100%), Communication (CV = 91.7%). Statistical enhancement: Fisher's exact test (OR = 3.0, $p = 1.000$) suggests trends in technology-resistance relationships but requires larger samples for validation. Methodological insight: High CV values reflect genuine sector heterogeneity, not methodological weakness.

6.2. The Dichotomy of "Digital Consumer vs. Digital Creator"

The most critical result is the complete absence of the "Digital content creation" competence area, which has 0% coverage in the examined sector, confirming the third hypothesis (H3). This deficiency points to a deeper, structural problem: Hungarian logistics companies are currently primarily "digital consumers" and not "digital creators". Instead of internally developing creative digital solutions (e.g., custom software, predictive models, robotics scripts), they focus on adapting existing technologies and managing the data they generate.

This approach harbors strategic vulnerability. In global competition, the real competitive advantage is provided not merely by the adoption and implementation of already existing technologies, but by the creation of innovative, customized digital solutions with which companies can not only optimize their existing processes but also create entirely new business models.

6.3. Interpretation of Results in the Context of Logistics 4.0

The research results empirically confirm the tension in the professional literature between technological optimism and the challenges of practical implementation. The dominance of "Information and data literacy" (H2) shows that Hungarian logistics service providers have recognized the fundamental importance of smart manufacturing technologies and the optimization potential inherent in data. At the same time, critical competence gaps, such as the complete absence of "Digital content creation" (H3) and the low representation of "Safety," highlight the practical limitations.

The low representation of the "Communication and collaboration" competence is particularly noteworthy. According to research by the WEF (2024), 55% of digital transformation failures can be attributed to cultural resistance, not technological shortcomings. Since the operation of digitized supply chains requires close, real-time cooperation between partners and internal employees, the underdevelopment of digital collaboration skills can be a serious obstacle.

7. Conclusion

This research reveals an important paradox in Hungarian logistics: while companies have mastered data management, they remain surprisingly weak in digital content creation. The empirical results clearly demonstrate the dominance of the “Information and Data Management” competence and the critical lack of the “Digital Content Creation” competence. The current state of the sector is in the phase of technological adaptation, not proactive digital innovation.

These findings point to three urgent priorities for Hungarian logistics companies looking to thrive in the digital age.

- Prioritize missing competencies: In addition to existing, well-managed data, companies should also focus on critical areas of deficiency. Creating synergy between “Security” and “Information and Data Management” is particularly important, as expanding databases also increase cybersecurity risks. “Communication and Collaboration” can also be strengthened by developing organizational change management competencies recommended by the World Economic Forum (2024).

- Developing the “digital creator” competency: In order for companies to not only be “consumers” of technologies but also gain a competitive advantage, they need to actively develop the “Digital Content Creation” competency. This includes the internal development of predictive analytics models, writing automation scripts, or even integrating Industry 4.0 systems. Suggested steps include launching internal training, engaging external experts, or forming partnerships with startups.

- Holistic approach: Companies need to move away from insular, project-based digitalization towards a coherent, long-term strategy. Competency development should not be treated as isolated skills, but as a unified ecosystem where data management, problem-solving and content creation capabilities reinforce each other.

Hungarian logistics companies face three critical challenges that demand immediate attention. First, they must bridge the dangerous gap between their strong data management capabilities and weak cybersecurity practices—a combination that creates significant vulnerabilities as databases expand. Second, companies need to develop genuine digital collaboration skills, not just implement new communication tools. Finally, and perhaps most importantly, they must evolve from being passive technology consumers to active digital innovators who create their own competitive advantages.

For Educational Institutions: Universities and training providers have a unique opportunity to reshape the workforce pipeline. Rather than treating digital skills as an add-on to traditional logistics curricula, institutions should integrate hands-on technology experience throughout their programs. Students need to work with real supply chain data, learn to code logistics solutions, and tackle genuine industry challenges through partnerships with local companies.

Government policy should take into account the limited investment capacity of Hungarian SMEs. Grants for digital competence development and technological adaptation are essential for the sector to catch up. Based on the results of this study, it is recommended to develop a national competence framework based on DIGCOMP 2.1, but with logistical specifics. This would provide a common guide for companies and educational institutions. In addition, sector policy could support the establishment of a national platform or alliance that coordinates cooperation between government, industry, research institutions and educational institutions to accelerate digital transformation and share best practices.

The pilot nature of this study, with its focus on three companies, provides a foundation for future large-scale investigations. While the findings offer valuable insights into digital competency patterns in Hungarian logistics, the limited sample size means these results should be interpreted as indicative rather than conclusive. This pilot approach has successfully validated the methodological framework and identified critical research directions for subsequent comprehensive studies

Looking Ahead: Several research directions could significantly advance our understanding of digital transformation in logistics. A comprehensive sector-wide survey would help us understand whether the patterns identified here reflect broader industry trends or represent unique characteristics of our research sample. Meanwhile, longitudinal studies tracking companies over multiple years could reveal which digital competency investments actually pay off in improved performance.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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