Digital Technologies and Education in Logistics in Kazakhstan: Pathways to Increasing Competitiveness and Technological Readiness

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Abstract. The digital transformation of transport and logistics systems requires not only modernization of infrastructure but also the development of educational models capable of preparing specialists for data-driven logistics environments. In corridor economies such as Kazakhstan, logistics competitiveness depends on the ability to integrate digital technologies into operational processes, including supply chain analytics, simulation modelling, digital twins, and platform-based coordination. However, the effectiveness of digital transformation is limited when educational systems do not provide sufficient competencies for working with advanced logistics technologies.

This study proposes a framework for evaluating the digital maturity of logistics education and its impact on technological readiness. A composite indicator, the Digital Logistics Education Index (DLEI), is introduced to measure the level of digitalization of logistics education based on infrastructure readiness, curriculum digitalization, industry integration, and research activity.

Using publicly available international statistics and national data, a pilot empirical assessment of digital readiness and logistics performance in Kazakhstan is conducted. The results indicate significant progress in digital connectivity and digital government development, while logistics performance indicators remain moderate, suggesting the presence of a competence gap.

The study proposes a modernization framework for logistics education based on simulation-based learning, digital twin laboratories, and cluster-based cooperation between universities and industry. The pilot calculation shows that the DLEI increased from 0.49 to 0.96 during the period of analysis.

Keywords: Industry 4.0, digital twins, supply chain analytics, simulation modelling, logistics performance, digital infrastructure.

1 Introduction

Digital technologies have become one of the main drivers of efficiency and competitiveness in modern transport and logistics systems. In this context, the concept of Logistics 4.0 reflects the integration of Industry 4.0 technologies into logistics processes, including the Internet of Things (IoT), big data analytics, cloud computing, artificial intelligence, and cyber-physical systems [1,2].

However, infrastructure alone does not guarantee high logistics performance. Even countries with improving connectivity and digital services may face delays, coordination failures, and low operational efficiency if the workforce lacks digital competencies. Kazakhstan is a representative case of a corridor economy. Located between Europe and Asia, it participates in major international transport corridors and seeks to strengthen its role in Eurasian logistics. In recent years, Kazakhstan has demonstrated significant progress in digital development: internet use has expanded, digital public services have improved, and the country has strengthened its e-government position. At the same time, logistics performance indicators remain moderate, suggesting that digital progress has not yet been fully translated into operational effectiveness. [6]

One important reason may be the insufficient digitalization of logistics education. Many educational programmes still emphasize traditional disciplinary content while only partially incorporating simulation modelling, supply chain analytics, digital twins, platform logistics, and data-driven decision making. As a result, graduates may not possess the competencies required for digital logistics environments. Although numerous studies address Industry 4.0, digital supply chains, and transport digitalization, there is still a lack of measurable approaches linking education modernization with technological readiness and logistics competitiveness. To address this gap, the present study proposes a Digital Logistics Education Index (DLEI) and applies it to Kazakhstan as a pilot case. The study addresses four research questions: RQ1 — Which competencies are required for digital logistics systems? RQ2 — How can the level of digitalization of logistics education be measured? RQ3 — What do empirical indicators show about Kazakhstan's readiness? RQ4 — How can modernization of logistics education improve competitiveness?

2 Problem statement

Despite rapid technological progress in transport and logistics, many countries struggle to convert digital development into higher logistics performance. Kazakhstan has achieved visible progress in digital infrastructure and digital government. Nevertheless, logistics performance has improved only slightly. This suggests that structural constraints remain. One of them is the competence gap: the mismatch between

technological requirements of modern logistics and the content of educational programmer. Many logistics curricula still focus on traditional theoretical content and do not sufficiently cover simulation modelling, data analytics, digital twins, platform logistics, and intelligent transport systems. Without such training, graduates may be unable to support the effective implementation of digital logistics technologies in practice.

3 Literature review

3.1 Digital transformation and Logistics 4.0

The transition to digital technologies has fundamentally changed logistics systems. Logistics 4.0 involves the application of Industry 4.0 technologies to supply chains, transport operations, and warehouse processes. These technologies enable real-time visibility, faster response to disruptions, and more efficient coordination. At the same time, their implementation requires new organizational practices and personnel capable of working with complex information systems [1–3].

3.2 Digital supply chains and platform-based logistics

Modern supply chains increasingly function as digital ecosystems in which manufacturers, carriers, warehouses, public agencies, and customers exchange information through common platforms. Platform-based logistics improves transparency, routing flexibility, and coordination efficiency [4].

3.3 IoT, blockchain, and data-driven logistics

IoT technologies enable continuous monitoring of vehicles, cargo, and infrastructure, allowing optimization of routes, prediction of delays, and enhancement of safety. Blockchain improves traceability and trust in supply chains by enabling secure and transparent storage of transactional data. The combined use of IoT and blockchain increases the complexity of logistics information systems and raises the importance of competencies in data management, cybersecurity, and system integration [7].

3.4 Simulation modelling and digital twins in logistics

Simulation modelling is widely used for analysing warehouses, terminals, and transport networks. Digital twins extend simulation by linking virtual models with real data flows, supporting monitoring and optimization in real time. Educational research shows that practical and simulation-based learning significantly improves the ability to work with complex systems [11]. Therefore, the inclusion of simulation environments and digital twin laboratories in logistics education is increasingly viewed as a necessary condition for preparing specialists for Industry 4.0 [12].

3.5 Education for Industry 4.0

The development of Industry 4.0 requires a shift from traditional knowledge-based curricula to competency-based educational models. Students must learn to solve practical problems using digital tools, real datasets, and modelling techniques. Cooperation between universities and industry, project-based learning, internships, and access to practical digital infrastructure improve educational quality and workforce readiness.

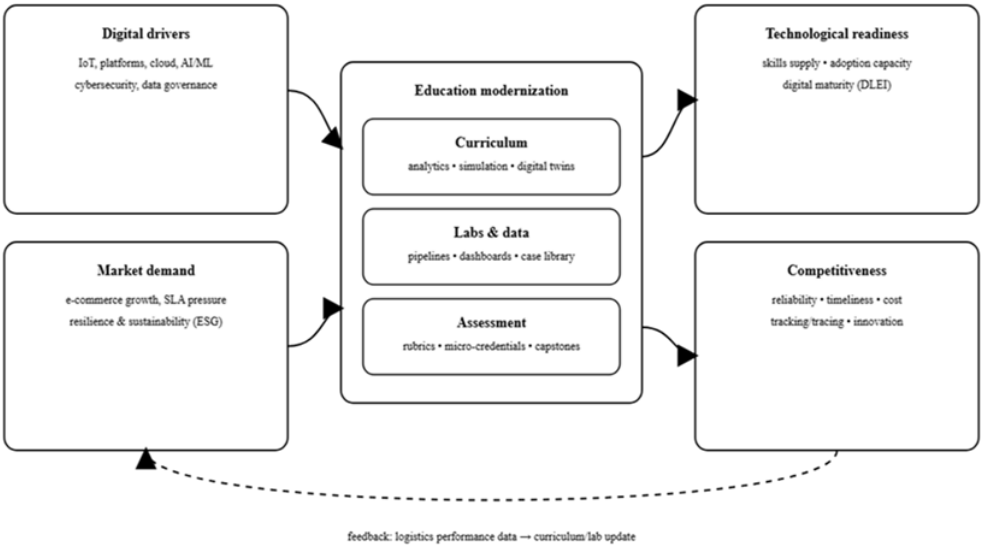


Fig. 1. Conceptual framework of digital logistics education and competitiveness.

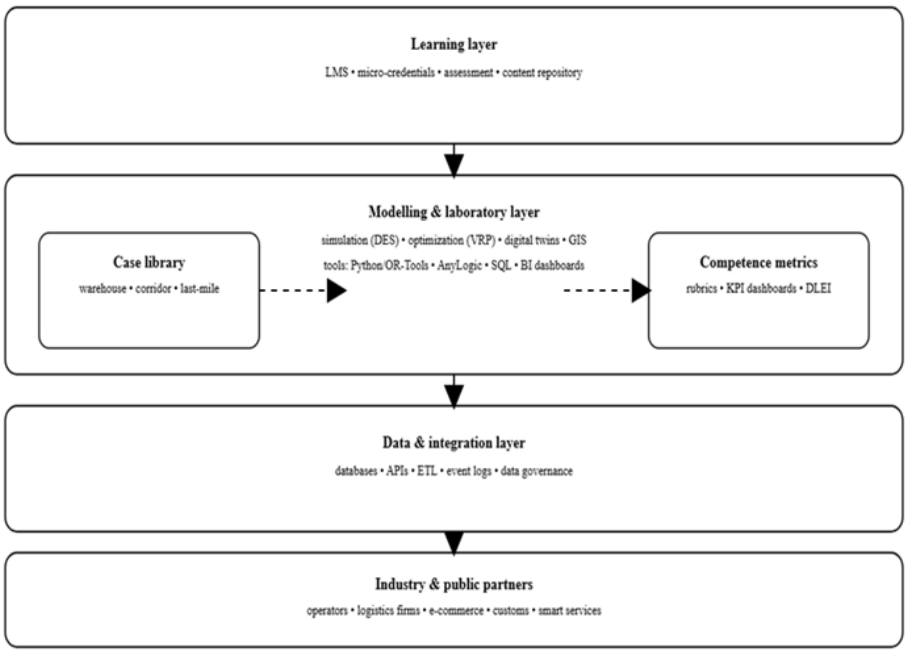


Fig. 2. Reference architecture of digital logistics education system.

4 Methodology

4.1 Research approach

The study uses a mixed methodological design combining conceptual modelling, statistical analysis, and scenario calculations. The main assumption is that logistics performance depends on three interrelated groups of factors: digital infrastructure, competence level, institutional integration. This approach is consistent with innovation systems theory, where technological development depends on the interaction of infrastructure, institutions, and human capital [17, 20].

4.2 Concept of Digital Logistics Education Index

To evaluate the level of digitalization of logistics education, a composite indicator called the Digital Logistics Education Index (DLEI) is introduced.

The index integrates four components that describe different aspects of education modernization: infrastructure readiness (IR), curriculum digitalization (CD), industry integration (II), research activity (RA).

The general form of the index is

$$\mathrm{DLEI} = w_1 \cdot \mathrm{IR} + w_2 \cdot \mathrm{CD} + w_3 \cdot \mathrm{II} + w_4 \cdot \mathrm{RA} \quad (1)$$

where:

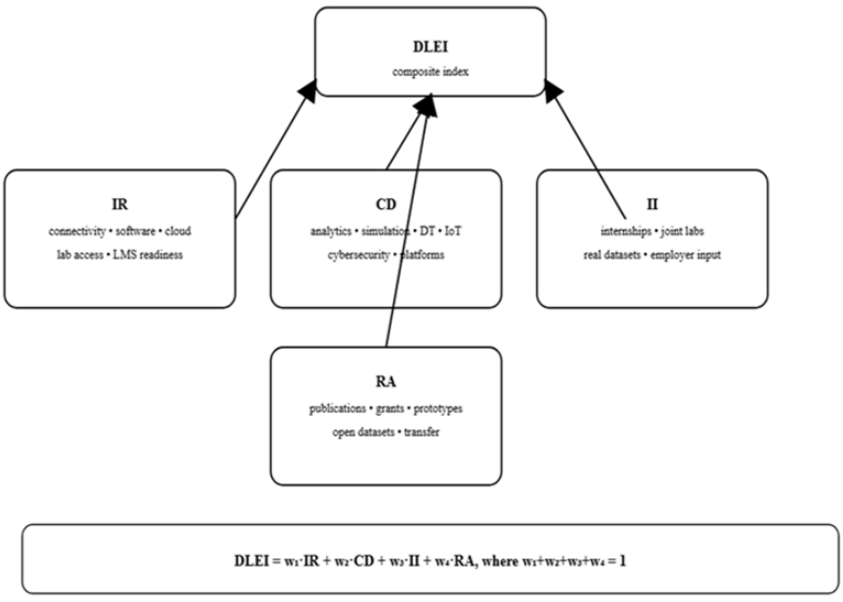


Fig. 3. Digital Logistics Education Index (DLEI) structure.

IR — infrastructure readiness; CD — curriculum digitalization; II — industry integration; RA — research activity; w_1, w_2, w_3, w_4 — weights

The weights satisfy:

$$w_1 + w_2 + w_3 + w_4 = 1 \tag{2}$$

Composite indices of this type are widely used in innovation, competitiveness, and digital readiness. The proposed index may be calculated for a country, region, or university [13,30].

4.3 Infrastructure readiness

Infrastructure readiness reflects the availability of digital tools required for modern education. Typical indicators include Internet access, broadband connectivity, availability of licensed software, access to cloud platforms, laboratory equipment. For macro-level analysis, only publicly available indicators can be used. Therefore, the following variables are selected: Internet users (% of population) Fixed broadband subscriptions per 100 people These indicators are widely used in international studies of digital development[14]. The normalized values are calculated using min–max scaling

$$\mathrm{N} = (\mathrm{X} - \mathrm{X_{min}}) / (\mathrm{X_{max}} - \mathrm{X_{min}}) = 1 \tag{3}$$

Where:
X — observed value
$\mathrm{X_{min}}$ — minimum
$\mathrm{X_{max}}$ — maximum

The infrastructure readiness component is calculated as

$$\mathrm{IR} = (\mathrm{N_1} + \mathrm{N_2}) / 2 \tag{4}$$

Where $\mathrm{N_1}$ — normalized Internet users

$\mathrm{N_2}$ — normalized broadband subscriptions

Curriculum digitalization

4.4 Curriculum digitalization

At the macro level, direct data on curriculum content is limited. Therefore, the study uses a proxy based on the UN E-Government Development Index (EGDI) ranking, if

countries with more advanced digital institutions also tend to have more developed digital educational environments. The UN E-Government Development Index ranking is selected as an indirect measure of digital institutional readiness, because countries with developed digital governments usually have more advanced digital education systems. The curriculum digitalization component is calculated as:

$$CD = (R_{max} - R) / (R_{max} - R_{min}) \quad (5)$$

Where:
R — country ranking
R_{max} — worst rank
R_{min} — best rank

Higher ranking corresponds to higher digitalization. Similar proxy approaches are used in studies of technological readiness when direct indicators are not available.

4.5 Research activity

Research activity reflects innovation capacity of universities. Possible indicators - Scopus publications, research grants, patents, projects, participation in digitalization programs. Research activity is important because universities with strong research capacity usually have more advanced educational programs. However, national-level data are limited, therefore this component is also excluded from pilot calculation. RA = not used in pilot model

4.6 Pilot version of the index

Because full data are not available, a simplified version of the index is used.

$$\text{Pilot DLEI} = 0.6 \cdot IR + 0.4 \cdot CD \quad (6)$$

The higher weight of infrastructure corresponds to recommendations of digital readiness studies, where connectivity is considered the basic condition for digital transformation [14]. This simplified model allows evaluation of macro-level readiness and may be used for time-series analysis.

4.7 Data sources

Empirical data used in the study are obtained from international and national databases. Main sources - World Bank World Development Indicators, World Bank Logistics Performance Index, United Nations EGDI, Bureau of National Statistics of Kazakhstan. These databases are widely used in transport and logistics research. The following variables are used by Internet users (%), Broadband subscriptions, EGDI ranking, LPI score, e-commerce volume.

Table. 1. Indicators used in the study

Indicator	Source	Meaning
Internet users	World Bank	Digital access
Broadband	World Bank	Connectivity
EGDI rank	UN	Digital readiness
LPI	World Bank	Logistics performance
E-commerce	Statistics RK	Demand for logistics

4.8 Model of influence of competence on logistics performance

To explain the role of education, a simplified analytical model is introduced.
Let
P — logistics performance
D — digital infrastructure
C — competence level
I — institutional integration

$$P = \alpha D + \beta C + \gamma I + \delta DC \tag{7}$$

where
DC — interaction between infrastructure and competence.
Such interaction terms are used in models of innovation systems [17].
Competence level depends on education.

$$C \approx DLEI \tag{8}$$

Substituting (8) into (7) gives

$$P = \alpha D + \beta DLEI + \gamma I + \delta D \cdot DLEI \tag{9}$$

This model explains why infrastructure alone does not guarantee high performance. If D is high but DLEI is low, performance remains limited.

4.9 Scenario model

To estimate economic effect, scenario modelling is used.
Let
V — volume of logistics operations
s — share of logistics costs
r — efficiency improvement
Total effect:

$$E = V \cdot s \cdot r \tag{10}$$

5 Empirical data for Kazakhstan

5.1 Digital development indicators

To evaluate the level of technological readiness, empirical data describing digital infrastructure, institutional digitalization, and logistics performance are analysed. Kazakhstan has demonstrated significant progress in digital development during the last decade. According to international statistics, the share of Internet users increased steadily, and the country improved its position in digital government rankings. High level of connectivity creates favourable conditions for implementation of digital technologies in education and logistics. However, the existence of infrastructure does not automatically lead to high performance. Therefore, it is necessary to compare digital indicators with logistics performance data. The main variables used in the empirical analysis are Internet users (% of population), fixed broadband subscriptions, UN EGDI ranking, Logistics Performance Index, volume of e-commerce. These indicators are widely used in studies of digital economy and transport system .

Table. 2. Digital indicators of Kazakhstan

Year	Internet users (%)	Broadband (/100)	EGDI rank	LPI
2015	70.8	12.7	–	–
2016	74.5	12.8	–	–
2017	76.4	13.8	–	–
2018	78.9	13.0	39	2.69
2019	81.8	13.1	–	–
2020	85.9	13.4	29	–
2021	90.9	13.9	–	–
2022	92.3	14.4	28	–
2023	92.8	14.3	–	2.70
2024	93.3	–	24	–

[9] World Bank, UN, Statistics Kazakhstan

The data shows steady growth of connectivity and digital government development. At the same time, the Logistics Performance Index remains almost unchanged, which indicates the existence of structural constraints.

5.2 4.2 Normalization of indicators

To calculate the Digital Logistics Education Index, the indicators must be normalized. Min–max normalization is used according to formula (3)

$$N = (X - X_{min}) / (X_{max} - X_{min})$$

For Internet users
$X_{min} = 70.8$
$X_{max} = 93.3$
For broadband
$X_{min} = 12.7$
$X_{max} = 14.4$
Normalized values are calculated for each year.

Table. 3. Normalized indicators

Year	N1 Internet	N2 Broadband
2015	0.00	0.00
2016	0.17	0.06
2017	0.26	0.65
2018	0.36	0.18
2019	0.49	0.24
2020	0.67	0.41
2021	0.89	0.71
2022	0.96	1.00
2023	0.98	0.94
2024	1.00	–

5.3 Calculation of infrastructure readiness

Using formula (4)

$$IR = (N_1 + N_2) / 2$$

The infrastructure readiness component increases over time, reflecting improvement of digital connectivity.

Table. 4. Normalized indicators

Year	IR
2015	0.00
2016	0.12
2017	0.46
2018	0.27
2019	0.37
2020	0.54

2021	0.80
2022	0.98
2023	0.96
2024	1.00

The results show rapid growth of digital infrastructure.

5.4 Calculation of curriculum digitalization proxy

Curriculum digitalization is estimated using EGDI ranking. Using formula (5)

$$CD = (R_{max} - R) / (R_{max} - R_{min})$$

Assume

$R_{max} = 193$

$R_{min} = 1$

Table. 5. Curriculum digitalization proxy

Year	Rank	CD
2018	39	0.80
2020	29	0.86
2022	28	0.87
2024	24	0.90

The improvement of ranking indicates increasing digital institutional readiness.

5.5 Calculation of DLEI

Using formula (6)

$$\text{Pilot DLEI} = 0.6 \cdot IR + 0.4 \cdot CD$$

Table. 6. Pilot DLEI values

Year	IR	CD	DLEI
2018	0.27	0.80	0.49
2020	0.54	0.86	0.67
2022	0.98	0.87	0.94

2024	1.00	0.90	0.96

The index shows steady growth of digital readiness. However, logistics performance does not grow at the same rate.

5.6 Comparison with logistics performance

To analyze the relationship between education readiness and logistics efficiency, the DLEI values are compared with the Logistics Performance Index.

Table. 7. Comparison of DLEI and LPI

Year	DLEI	LPI
2018	0.49	2.69
2023	0.95	2.70

The results show that despite strong growth of digital readiness, logistics performance remains almost unchanged. This confirms that infrastructure alone is not sufficient. Competence level and institutional factors play an important role. Similar conclusions are obtained in studies of digital transformation, where human capital is considered one of the main determinants of performance.

5.7 Demand for digital logistics

Another indicator of the need for modernization is the rapid growth of e-commerce. Electronic trade requires advanced logistics systems, including automated warehouses, routing algorithms, and real-time tracking. According to official statistics, the volume of e-commerce in Kazakhstan exceeded two trillion tenge, which creates high demand for specialists with digital competencies.

Table. 8. E-commerce growth

Year	Volume (bn KZT)
2018	684
2020	1300
2022	2100
2024	2443

5.8 Interpretation of results

The empirical analysis shows three important conclusions:
1. Digital infrastructure in Kazakhstan has improved significantly.

2. Institutional digital readiness is growing.
3. Logistics performance remains moderate.
This indicates the existence of a competence gap. The results support the hypothesis that modernization of logistics education is necessary to convert digital readiness into real performance.

6 Scenario modelling of the impact of education modernization

6.1 Rationale for scenario modelling

The influence of education on logistics performance is indirect and cannot be evaluated using simple statistical comparison. The effect of modernization appears through improvement of decision quality, better use of digital technologies, and reduction of operational errors. To estimate the potential effect, the following simplified model is introduced.

Let
V — total volume of logistics-related operations
s — share of logistics costs in turnover
r — efficiency improvement due to competence growth

$$E = V \cdot s \cdot r \tag{11}$$

This formula allows evaluation of the possible savings obtained through modernization of education.

6.2 Scenario parameters for Kazakhstan

The volume of logistics-related operations may be approximated using e-commerce turnover, which strongly depends on logistics efficiency. According to official statistics, the volume of electronic trade in Kazakhstan exceeded two trillion tenge in recent years.
Assume
V = 2.4 trillion KZT
s = 0.10–0.15
r = 0.02–0.08
The values of r correspond to typical efficiency gains obtained after introduction of digital technologies in supply chains.

Table. 9. Scenario calculations

s	r	Effect (bn KZT)
0.10	0.02	4.8
0.12	0.02	5.8
0.15	0.02	7.2

0.10	0.05	12.0
0.12	0.05	14.4
0.15	0.05	18.0
0.10	0.08	19.2
0.12	0.08	23.0
0.15	0.08	28.8

Model of competence influence
To describe the relationship between infrastructure, competence, and performance, a simplified analytical model is used.
Let
P — logistics performance
D — digital infrastructure
C — competence level
I — institutional integration
Assume

$$P = \alpha D + \beta C + \gamma I + \delta DC \tag{12}$$

where
DC — interaction between infrastructure and competence
Such interaction models are used in studies of innovation systems and technological readiness.

Competence level depends on education:

$$C \approx DLEI \tag{13}$$

Substituting (13) into (12) gives

$$P = \alpha D + \beta DLEI + \gamma I + \delta D \cdot DLEI \tag{14}$$

The model explains why high infrastructure without adequate education does not guarantee high performance.

7 Conclusions

Digital transformation is fundamentally changing the structure of transport and logistics systems. Modern supply chains require specialists able to work with data, simulation models, and digital platforms.

The analysis conducted in this paper shows that Kazakhstan has achieved significant progress in digital infrastructure and digital government development. However, logistics performance indicators remain moderate, which indicates the existence of a competence gap. To evaluate the level of digitalization of logistics education, the Digital Logistics Education Index was proposed. The index integrates infrastructure readiness, curriculum digitalization, industry integration, and research activity. A pilot calculation demonstrates that macro-level conditions in Kazakhstan are favorable for

digital education, but institutional changes in universities are still required. Scenario modelling shows that modernization of education may lead to significant economic effects. Even small improvements in efficiency achieved through better training of specialists may result in large savings in logistics operations. The study confirms that modernization of logistics education should be considered a strategic priority. Investments in laboratories, digital curricula, and cooperation with industry may produce long-term effects comparable to infrastructure projects. The proposed framework may be used by universities, policymakers, and transport organizations to monitor progress of digital transformation and to improve competitiveness of the transport and logistics complex.

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