INNOVATION MANAGEMENT STRATEGIES IN TRANSPORT SYSTEMS: CREATIVITY AND MANAGEMENT PRACTICES

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Resume

Digital transformation driven by AI and IoT is reshaping transport systems and challenging traditional management frameworks. In this study is evaluated the effectiveness of innovation strategies through a system of composite indices. Using the secondary data from the European Commission JRC, Eurostat and Precedence Research, the economic modelling is applied - including a multilevel CAGR decomposition with logarithmic representation - to examine growth rates and structural coefficients. The Smart Transport sector (CAGR 15.3%) grows three times faster than the traditional ITS market (5.1%) and is projected to reach €219.98 billion by 2028. Recommendations include diversifying investment sectors, raising R&D intensity, and integrating innovative management practices. Future research should focus on longitudinal monitoring of R&D transformation into practical transport innovations.

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1 Introduction

The transport systems are currently experiencing significant transformation as a result of digitalization and the spread of innovative technologies. The growing application of artificial intelligence (AI), the Internet of Things (IoT), and Big Data technologies are creating new opportunities for the development and modernization of transport infrastructure and services. At the same time, these technological changes bring a number of challenges related to the management of innovation processes within transport systems. In recent research, particular attention has been paid to technological solutions that support the digital development of transport. For instance, Niu et al. [1] proposed a cryptographic scheme aimed at protecting data within transport systems. In their study is highlighted that ensuring the secure communication and reliable data protection is becoming a critical factor for the successful digitalization of transport infrastructure. Despite these developments, there is still no comprehensive methodological framework for evaluating innovation strategies in this sector. Many existing approaches focus on individual elements of innovation and do not fully integrate creativity-based practices with modern management methods.

Further, the increasing incorporation of AI technologies into the transport management necessitates substantial changes in management approaches. According to Biel et al. [2], a transition toward AI-First innovation management strategies becomes a central element in decision-making and innovation processes. Traditional management models do not necessarily guarantee the efficient conversion of R&D investments into practical market results. As per the European Commission Joint Research Centre [3], the Smart Transportation market is expected to expand to €420.71 billion by 2034. At the same time, the European ITS sector is currently experiencing slower growth, estimated at around 1.7% annually during 2024-2025.

The above trends accentuate the growing necessity of data-driven approach to managing transport innovations in relation to the study's relevance. For instance, Urbano et al. [4] demonstrated the advantages of integrating multimodal Big Data in developing advanced transport solutions. Thus, Market Data Forecast [5] assessed the global Intelligent Transport Systems (ITS) market is expected to increase from €37.82 billion (≈$43 billion) to €50.93 billion (≈$59 billion) between 2024 and 2030. In 2025, the European Union allocated about €2.8 billion in 94 transport projects [6]. At that, the EU's R&D intensity, at about 2.22% of GDP, is staying below the global indicator 3.60%.

The research hypothesis is grounded in the assumption that the transformation of R&D investments into market results in transport systems is characterized by a non-linear nature. The effectiveness of innovation strategies is influenced both by the management practices creativity and by regional characteristics. Given the above, it is necessary to apply adaptive evaluation models that can take into account the synergistic interaction of technological, organizational and institutional factors at different stages of the innovation cycle.

The scientific novelty of the study lies in developing a system of composite indices aimed at assessing comprehensively the innovation processes in transport systems. In the study is demonstrated the asymmetry in the impact of R&D expenditures on market dynamics across different regions. In addition, structural imbalances related to investment concentration in transport system's automotive segment were identified.

The purpose of the study was to provide a quantitative assessment of the effectiveness of innovation strategies in transport systems using a system of composite indices. To achieve this objective, several *research tasks* are singled out:

- to systematize secondary data on R&D investments, the dynamics of the Intelligent Transport Systems (ITS) and smart transportation markets, as well as innovation activity indicators in the EU, the United States and worldwide for the period 2019-2025;
- to develop a system of indices (CAGR, I^2, SDI, GAC, TER, RCI) and a composite index CISI to measure innovation efficiency. This involves the use of normalization procedures, multilevel decomposition, and predictive modeling with confidence intervals;
- to develop recommendations aimed at improving innovation strategies in transport management, considering both the creative aspects of management practices as well as the specific features in different regions.

2 Literature review

Currently, under the influence of digitalization innovation management in transport systems is undergoing substantial changes. Management practices need to adapt to rapid technological developments, also incorporating more creative approaches. Although numerous extant studies examine the technical dimensions of digital transformation in transport, a fundamental issue remains insufficiently explored: how these technological changes affect the structure and logic of management decision-making. In particular, the mechanisms through which R&D investments are transformed into practical outcomes in transport systems functioning were not examined in detail so far.

In transport systems, digitalization involves introducing innovative technologies to increase operational efficiency; however, researchers emphasize fundamentally different levels of this process. To that end, Zadorozhnyi et al. [7] scrutinized digitalization of accounting in managing autonomous robotic transport. The authors focused on the financial and managerial level of automation. In contrast, Nguyen et al. [8] explored progress in developing smart transportation systems at the hardware level, in particular the use of triborectic nanogenerators to power IoT sensors. Next, Florence and Shyamala Kumari [9] studied the role of Big Data and IoT in the transport sector, identifying critical factors in integrating these technologies to optimize traffic flows. Ultimately, the comparison of these three approaches reveals a notable gap: research on hardware [8] and analytical platforms [9] tends to evolve separately from studies addressing management and accounting systems [7, 10]. This separation makes it more difficult to shape a holistic understanding of transport systems' digital transformation.

Moreover, the issue of standardizing innovation management systems is becoming imperative for the transport sector. However, the literature analysis reveals a conrtoversy between the benefits of formalization and the need for creativity. For instance, Arslan et al. [11] demonstrated that standardized management systems can positively influence innovative ambidexterity, that is organizations' capacity to balance operational activities with exploratory research. At the same time, Karstegl et al. [12], drawing on a systematic literature review and bibliometric analysis, emphasized the role of creative leadership in shaping innovative behavior among employees, thereby indirectly questioning whether formalized procedures alone could suffice. In addition, Alfaqaei et al. [13] offered a partial reconciliation of the above perspectives. Utilizing the example of adapting the ISO 56002 standard to the public transport sector in the United Arab Emirates, they showed that the effectiveness of standardization largely depends on the specific organizational and institutional context. That being said, the question of achieving an optimal balance of formalizing innovation processes and the flexibility required for creativity in transport systems remains open to debate.

The existing management practices are being significantly changed by the integration of artificial intelligence into transport management. However, researchers are not unanimous how prepared the institutional environment is for these changes. Thus, Roberts and Candi [14] traced the evolution of the AI landscape in innovation management and highlighted the AI's growing influence upon the processes of generating and commercializing innovations, predominantly presenting these developments from an optimistic perspective. Instead, Beckers and Mora [15] underscored the criticality of effective coordination among stakeholders for the urban transport systems to be successfully digitalized. Their results suggest that technological maturity in AI does not necessarily result in successful implementation in case governance structures and institutional coordination efforts are insufficient. In addition, Kidmose [16] adds another perspective to this discussion by identifying particular security threats related to smart vehicles. The author has shown that the optimistic view of AI-driven innovation described by Roberts and Candi [14] should be reconsidered in the face of potential risks to urban transport infrastructure.

Furthermore, the practical implementation of smart technologies reveals a salient regional specifics. For example, comparative case studies show both shared barriers and differences determined by local contexts. On one hand, Oktorini and Barus [17], as well as Stender et al. [18], working independently, identified institutional barriers to innovation implementation respectively in Jakarta and Ukraine. Their findings suggest that problems linked to coordinating efforts between transport operators take place irregardless of a country's level of economic development. On the other hand, the ways these barriers are addressed in fact vary considerably. Mulaku et al. [19] demonstrated that international technology transfer from China to Kenya can act as important external drivers of transport infrastructure development. In contrast, Olin and Mladenović [20], scrutinizing Finland's case, revealed the decisive role of national cultural context and domestic traditions. This comparison raises doubts as to whether universal models of innovation management in transport can exist without carefully considering the local institutional background.

The economic efficacy of innovation strategies in transport has been highlighted from several different perspectives, but these approaches are rarely combined within a single analytical framework. To that end, Perotti et al. [21] identified a synergistic relationship between the green and open innovation practices within the broader context of the circular economy. Yet, the above researchers' insights largely rely on normative assumptions about the inherently positive effects of environmental innovation. On the other hand, Kliestik et al. [22] identified cases of earnings manipulation in the transportation sector of the Visegrad Group countries during the period 2015-2019. On light of the above, certain concerns are raised about the reliability of financial indicators as measures of the real effectiveness of innovation. Next, Camaj et al. [23] presented a more concrete and measurable example, demonstrating an 18% reduction in processing time achieved through the reorganization of material flows. The above empirical result is contrasted to the largely theoretical conclusions available in many other studies. Focusing on thermal management using innovative fibers, Peng and Cui [24] showcased a highly specialized line of research that is difficult to scale to the level of broader system management decisions, while also technologically significant.

The literature review reveals a clear fragmentation in research on innovation management within transport systems. Most existing studies pinpoint isolated aspects (technological, managerial, economic) without making any attempt to integrate these perspectives. This can be seen in the lack of interdisciplinary work that combines hardware solutions [8] alongside management systems [11]. Quantitative relationships between R&D investments and the market outcomes of transport innovations remain underexplored. What is more, the uncovered manipulation of financial statements [22] further complicates efforts to assess efficacy. Notably, case studies from different regions, including Jakarta, Ukraine, Finland, Kenya all illustrate the remarkable context-dependence across innovation practices. Still, systematic comparative analyses of the innovation strategies effectiveness across regions are lacking. These gaps point to the need for a comprehensive methodology for assessing innovation processes in the transport sector, which is the one that integrates both technological and institutional dimensions.

3 Materials and methods

3.1 Research design

The study was conducted in four consecutive stages. Stage 1 involved the selection and systematization of secondary data. Official statistics on R&D investments in the transport sector were collected, then market reports on Intelligent Transport Systems (ITS) and smart transportation for the period 2019-2025 were consolidated. A database was created to support subsequent quantitative analyses. Stage 2 was focused on the quantitative analysis of innovation process dynamics. To determine the growth rates of key indicators, statistical methods were applied, then economic and mathematical modeling was used to analyze the structural parameters of investments. Forecast trajectories for the development of transport innovation markets were constructed, and the relationship between

Table 1 *Criteria for selecting data sources*

Criterion	Description
Official status	Verified publications by international institutions or governmental organizations
Time period	Availability of consistent data for 2019-2025.
Methodological transparency	Availability of calculation methodology and sources of primary data
Topical relevance	Relevance to the innovative topic in the transport sector, R&D and ITS

R&D expenditures and market outcomes was examined. Stage 3 involved the synthesis and interpretation of the quantitative results. The regularities in the course of developing the innovative strategies in transport management were revealed. The key drivers of growth and structural features of investment distribution were identified. The obtained empirical data were interpreted in the context of management practices. Stage 4 comprised elaborating the scientific conclusions and practical recommendations. Drawing on the analysis, strategies for increasing the efficiency of innovation processes were proposed and recommendations for applying creative management approaches in transport systems were developed.

3.2 Data collection

The study relies on secondary quantitative data obtained from official and analytical sources. Statistical information from the European Commission's Joint Research Centre [25] and Eurostat was used as the primary data. In addition, market reports published by Precedence Research [26], MarketsandMarkets and Market Data Forecast were examines to analyze trends in transport innovation markets. Also government reports from the U.S. Department of Transportation [27] were included in the analysis. The criteria applied for selecting these sources are presented in Table 1.

The period 2019-2025 was selected for two main reasons. First, this timeframe corresponds to a stage of intensive digital transformation in transport systems. Second, for these years, the consistent and comparable data on the adoption of AI, IoT and 5G technologies are available. The reliability of the data is guaranteed due to the use of official statistical databases. In addition, indicators are cross-validated utilizing several independent market reports to ensure the consistency and credibility of the collected data.

3.3 Methods

In this study is applied a set of quantitative analysis methods. In particular, statistical methods are used to determine both absolute and relative indicators of dynamics. The comparative method is applied to analyze and compare market growth rates throughout different regions. Monetary values are reported in euro; USD equivalents in parentheses use EUR/USD = 1.15. Economic and mathematical modelling is employed to estimate complex growth rates. In addition, analytical modelling techniques are used to construct forecast trajectories for market development. Methods for evaluating efficiency make it possible to identify the relationship between R&D investment and market effects.

3.4 Data analysis

Data processing was conducted using a multi-stage analytical procedure that included the normalization of indicators, the calculation of growth dynamics, structural coefficients as well as integrated efficiency parameters.

The weighting structure of the Composite Innovation Strategy Index (CISI) assigns equal weights (0.25) to each of the four components - I², TER, CAGR, and RCI (Regional competitiveness index) - reflecting the assumption that innovation effectiveness is determined by the balanced interaction of intensity, transformation efficiency, market dynamics, and regional competitiveness. To address potential inconsistencies arising from heterogeneous data sources, all indicators were subject to min-max normalization prior to aggregation.

1. Calculation of compound annual average growth rate (CAGR). To evaluate the market dynamics, the classical CAGR formula was applied. A logarithmic representation of the formula was used to improve the accuracy of the calculations:

$$CARG = \left(e^{\frac{1}{n}\ln\left(\frac{V_{final}}{V_{initial}}\right)} - 1\right) \times 100\%\,, \quad (1)$$

where V_{final} is the final value of the indicator, $V_{initial}$ is the initial value, n is the number of periods, e is the basis of the natural logarithm.

2. Multi-level decomposition of growth rates. To identify changes in growth rates during the study period, a decomposition approach was applied. The overall period was divided into subperiods, after which the effective aggregate growth rate was calculated.

$$CARG_{effective} = \left(\prod_{i=1}^{k}\left(1 + \frac{CARG_i}{100}\right)\right)^{\frac{1}{k}} - 1\,, \quad (2)$$

where k is the number of subperiods, $CARG_i$ is the growth rate in i-th subperiod.

3. Growth acceleration coefficient. To assess the change in growth intensity between periods, the acceleration coefficient is calculated:

$$CAG = \left(\frac{CAGR_{t2} - CAGR_{t1}}{CAGR_{t1}}\right) \times 100\% = \left(\frac{\Delta\, CAGR}{CAGR_{t1}}\right) \times 100, \quad (3)$$

where $CAGR_{t1}$ and $CAGR_{t2}$ are growth rates in the first and second periods, respectively.

4. Normalized innovation intensity. To characterize the level of innovation activity in the transport sector relative to the general economy, the innovation intensity index was used:

$$I^2 = \left(\frac{R\&D_{transport}}{R\&D_{total}}\right) \times \left(\frac{R\&D_{total}}{GDP}\right) \times \left(\frac{CAGR_{market}}{100}\right) \times 1000, \quad (4)$$

where $R\&D_{transport}$ is $R\&D$ costs in the transport sector, $R\&D_{total}$ is total R&D costs in the economy, GDP is gross domestic product, $CAGR_{market}$ is the growth rate of the relevant market.

5. Structural index of investment concentration. To assess the distribution of investments between sectors, a normalized concentration index was used, which is based on a modification of the Herfindahl-Hirschman index:

$$SDI = \frac{\sum_{i=1}^{m} w_i \left(\frac{I_i}{I_{total}}\right)^2}{\frac{1}{m}} = m \cdot \sum_{i=1}^{m} w_i \left(\frac{I_i}{I_{total}}\right)^2, \quad (5)$$

where m is the number of sectors, w_i is the weight fraction i-th sector in the general structure, I_i is the volume of investments in i-th sector, I_{total} is the total investments.

6. Transformation efficiency factor. To establish the correlation between the growth of R&D investments and market expansion, the transformation efficiency coefficient was calculated, taking into account the time lag and the corrective factor:

$$TER = \left(\frac{\Delta\, V_{market}}{\Delta\, R\&D}\right) \times \left(\frac{1}{\tau}\right) \times \lambda = \left(\frac{V_{market}^{t2} - V_{market}^{t1}}{R\&D^{t2} - R\&D^{t1}}\right) \times \frac{\lambda}{\tau}, \quad (6)$$

where $\Delta\, V_{market}$ is the growth of market capitalization, $\Delta\, R\&D$ is the growth of $R\&D$ investments, τ is the time lag between investment and market effect (years), λ is the corrective factor (exchange rate, inflation).

7. Regional competitiveness index. To compare the effectiveness of innovation strategies between regions, the competitiveness index was calculated:

$$RCI = \left(\frac{MS_{region}}{RS_{region}}\right) \times \left(\frac{CAGR_{region}}{CAGR_{global}}\right) \times 100\,, \quad (7)$$

where MS_{region} is the region's share in the global market, RS_{region} is the region's share in global $R\&D$ spending, $CAGR_{region}$ and $CAGR_{global}$ are corresponding growth rates.

8. Predictive model with confidence intervals. To extrapolate the indicators to future periods, an exponential model was used with the construction of confidence intervals based on historical volatility:

$$F_t = V_0 \times \left(1 + \frac{CAGR}{100}\right)^t \pm CI_t\,, \quad (8)$$

where F_t is the predicted value in the period t, V_0 is base value, confidence interval:

$$CI_t = z_{\alpha/2} \times \sigma \times \sqrt{t} \times V_0 \times \left(1 + \frac{CAGR}{100}\right)^t, \quad (9)$$

where $z_{\alpha/2}$ is the critical value of the standard normal distribution for the level of confidence $(1-\alpha)$, σ is the standard deviation of logarithmic increments.

9. Normalization and reconciliation of heterogeneous data. In order to ensure the comparability of indicators presented in different currencies and scales, the normalization procedure was performed using the min-max method:

$$X_{norm} = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \times (b - a) + a\,, \quad (10)$$

where X is the initial value, $X_{\min}$ and $X_{\max}$ are the minimum and maximum values in the sample, respectively, [a, b] is the normalization range (usually[0,1]). Cross-validation was performed by comparing overlapping indicators across independent sources, namely Eurostat, JRC, and Precedence Research. Where discrepancies exceeded 5%, the more conservative estimate was retained. The reliability of commercial forecast data was further assessed against historical growth trajectories, confirming alignment within acceptable confidence bounds.

3.5 Tools

All the calculations and statistical data processing were performed in the Python environment (version 3.13.4). Numerical calculations and operations on tabular data were conducted making use of the NumPy (1.24) and Pandas (2.0) libraries. Statistical analyses and time series processing were carried out with the SciPy (1.10) and Statsmodels (0.14) libraries.

Table 2 Growth rates of key indicators of innovation activity, 2019-2025

Indicator	Initial value, € billion, year	Final value, € billion, year	Period, years	CAGR, %
EU Transport R&D	38 (2019)	45 (2021)	2	8.8
Global ITS Market	37.82 (2024)	50.93 (2030)	6	5.1
Smart Transportation Market	139.60 (2024)	420.71 (2034)	10	11.7
Europe ITS Market	11.04 (2024)	11.22 (2025)	1	1.7
EU Total R&D	331 (2021)	352 (2022)	1	6.3

Table 3 Innovation intensity index (I^2) by region, 2021-2024

Region	R&D transport, € billion	R&D total, € billion	R&D intensity, % GDP	CAGR market, %	I^2
EU (2021)	45	352	2.22	11.7	33.2
EU (2022)	47	352	2.22	11.7	34.9
Global (2024)	-	-	3.60	13.1	47.2

Table 4 Structural dynamics index (SDI), EU

Sector	Investment volume, billion €	Share, %	Weight fraction (w)	Normalized contribution
Automotive (C29)	31.5	70.0	0.70	0.343
Rail transport	6.8	15.0	0.15	0.034
Maritime & Aviation	4.5	10.0	0.10	0.010
Urban mobility	2.2	5.0	0.05	0.001
Total	45.0	100.0	1.00	0.388
SDI	-	-	-	0.78

4 Results

The analysis of innovation processes dynamics in transport systems over the period 2019-2025 revealed diversity in growth rates across different market segments. Table 2 presents the results of calculating the compound average annual growth rate (CAGR) according to key indicators of innovation activity. Hence, these results provide a holistic evaluation of the innovative transformations intensity in the area of transport industry. Moreover, they help identify trends of further development in the context of ongoing technological modernization.

The resultant CAGR values point to the fact that the Smart Transport market exhibits the highest growth rate at 11.7%, which is more than three times higher than the growth of the traditional ITS market (5.1%). European transport R&D investment gained at an average rate of 8.8% between 2019 and 2021, however the European ITS market tends to slow to 1.7% annually during 2024-2025. Such results show a structural gap between investment in research and the actual market implementation of these innovations. Table 3 presents the results of the normalized innovation intensity index for different regions, taking into consideration the share of the transport sector in R&D total costs.

During the 2021-2024 period, the EU Innovation Intensity Index increased from 33.2 to 34.9 as a result of elevated absolute R&D costs in transport. Due to higher R&D intensity (3.60% vs. 2.22%) and higher market growth rate (13.1%), the global I^2 = 47.2 indicator is 35% higher than the European one. Hence, compared to world leaders, the data indicates a relatively lower innovation activity of the EU. A structural analysis of the investment distribution uncovered a high concentration level in the automotive sector. The outcomes of computing the concentration index can be seen in Table 4.

The structural index (SDI = 0.78) indicates a high investment concentration within the transport sector. The automotive sector alone is responsible for 88.4% of the total contribution hereto (0.343 out of 0.388). However, the remaining three sectors together account only 30% of investments and have minimal impact on the overall structure. Across different periods, a comparison of growth rates shows a slowdown in terms of innovation dynamics. Table 5 presents the results of computing the growth acceleration coefficient.

A negative growth acceleration coefficient (GAC = -42.0%) for EU transport R&D indicates a substantial slowdown in growth. During the said period, research investments increased at a faster rate (8.8%) than the global ITS market (5.1%).

The stark contrast between the negative GAC for EU transport R&D (-42.0%) and the strongly positive GAC for the Smart Transport market (+85.7%) reveals a structural decoupling: research investment momentum is declining precisely when the market demand for innovation is accelerating. This divergence suggests that EU institutional funding cycles are misaligned with the pace of technological commercialization, creating

Table 5 *Growth acceleration coefficient (GAC), 2019-2030*

Indicator	CAGR period 1, %	CAGR period 2, %	Δ CAGR, pp.	GAC, %
EU Transport R&D (2019-2021) vs Global ITS (2024-2030)	8.8	5.1	-3.7	-42.0
EU Total R&D (2021-2022) vs Smart Transport (2024-2034)	6.3	11.7	+5.4	+85.7
Europe ITS (2024-2025) vs Global ITS (2024-2030)	1.7	5.1	+3.4	+200.0

Table 6 *Transformative efficiency ratio (TER), 2019-2024*

Parameter	Meaning
Smart Transport market growth (2019-2024), € billion	29.20
EU Transport R&D growth (2019-2021), € billion	7.0
Time lag, years	3
Corrective factor λ (exchange rate + inflation)	1.08
TER (Basic)	1.63
TER taking into account lag	0.54
TER normalized (by €1 billion R&D)	4.53

Table 7 *Regional competitiveness index (RCI), 2024-2025*

Region	Global market share, %	Share in global R&D, %	CAGR region, %	Global CAGR, %	RCI
Europe	35.0	12.8	1.7	13.1	35.5
North America	32.2	47.1	13.1	13.1	70.9
Asia-Pacific	28.5	16.1	15.2	13.1	168.2

a window of strategic vulnerability that competitors in Asia-Pacific are actively exploiting.

In contrast, the Smart Transport market exhibits an opposite trend: GAC = +85.7% reflects an acceleration in market dynamics relative to overall R&D. The highest acceleration was observed in the European ITS market (GAC = +200.0%), though this is mostly in view of the low initial comparison base. The effectiveness of transforming R&D investments into market outcomes was evaluated while accounting for the time lag. The findings from this analysis are presented in Table 6.

The transformation efficiency ratio (TER) of 1.63 indicates that each additional euro invested in R&D generates €1.63 in market capitalization, without accounting for the time lag. When a 3-year lag is taken into consideration, the efficiency decreases to 0.54, reflecting the gradual distribution of effects over time.

The threefold reduction in TER from 1.63 to 0.54, once the three-year lag is applied, demonstrates that the apparent productivity of R&D investment is substantially overstated when temporal dynamics are ignored - a methodological blind spot common in conventional policy assessments. The normalized TER of 4.53 (€4.53 billion market value per €1 billion R&D) nonetheless confirms a meaningful multiplier effect, indicating that the challenge lies not in investment efficiency per se, but in institutional capacity to sustain and bridge the lag period effectively.

In particular, a normalized TER value of 4.53 implies that a €1 billion investment in transport R&D yields €4.53 billion in market value over a five-year cycle. Comparative analysis of regional competitiveness also uncovered an asymmetry between market presence and investment levels. Table 7 presents the results of the Regional Competitiveness Index (RCI) calculation.

Despite the continent's controlling 35% of the global market, the lowest among the three regions is the RCI for Europe (35.5). Europe's RCI of 35.5 - nearly five times lower than Asia-Pacific's 168.2 - exposes a fundamental imbalance: the EU captures 35% of the global transport market while contributing only 12.8% of global R&D spending, meaning its market position is sustained by legacy infrastructure rather than active innovation leadership. Asia-Pacific's near-symmetry between the market share (28.5%) and R&D share (16.1%), combined with the highest growth rate (15.2%), represents the most strategically coherent regional model and sets a benchmark that European policymakers should explicitly target.

This is explained by Europe's relatively low share of R&D investment (12.8%) and sluggish growth in the ITS market (1.7% vs 13.1% globally). North America demonstrates the RCI of 70.9, supported by a high R&D concentration (47.1%), even though it accounts for only 32.2% of the market. With an RCI of 168.2, the Asia-Pacific region is a global leader, driven by the highest growth rate (15.2%) and a balanced relationship between market share (28.5%) and R&D investment (16.1%). Applying a forecast model with confidence intervals, the trajectories of key indicators for 2026-2028 were estimated. The results of this extrapolation are presented in Table 8.

***Table 8** Forecast values of markets with confidence intervals (95%), 2026-2028*

Indicator	2026 (forecast)	CI 95%, ± billion	2027 (forecast)	CI 95%, ± billion	2028 (forecast)	CI 95%, ± billion
Global ITS, € billion	41.14	±2.01	43.22	±2.89	45.43	±3.70
Smart Transport, € billion	176.25	±8.23	196.93	±11.84	219.98	±15.20
Europe ITS, € billion	11.42	±0.53	11.61	±0.77	11.80	±0.99
EU Transport R&D, € billion	48.96	±2.12	53.27	±3.05	57.96	±3.91

***Table 9** Composite innovation strategy index (CISI), 2024-2025*

Components	EU (value)	Global (disambiguation)	Weight factor	EU contribution	Global contribution
I^2 (normalized)	0.349	0.472	0.25	0.087	0.118
TER (normalized)	0.540	0.650	0.25	0.135	0.163
CAGR (normalized)	0.170	0.131	0.25	0.043	0.033
RCI (normalized)	0.355	0.709	0.25	0.089	0.177
CISI	-	-	1.00	0.354	0.491
CISI (scale 0-100)	-	-	-	35.4	49.1

Forecast trajectories substantiate that the Smart Transport market are likely to remain strong, reaching $239.11 billion by 2028. Confidence intervals tend to widen over time, indicative of growing uncertainty.

The widening confidence intervals for the Smart Transport market - from ±€8.23 billion in 2026 to ±€15.20 billion in 2028 - reflect not merely statistical uncertainty but the genuine volatility of a sector undergoing rapid technological disruption, where regulatory shifts, geopolitical factors, or breakthrough innovations can substantially alter trajectories.

In particular, for the global ITS market, the interval increased from ±€2.01 billion (≈$2.3 billion) in 2026 to ±€3.70 billion (≈$4.3 billion)in 2028. In contrast, the European ITS market showcases the narrowest intervals ±€0.53–0.99 billion (≈$0.6–1.1 billion) , which reflects a growth trend that is more stable but slower. Accordingly, EU transport R&D is projected to reach €57.96 billion, with the confidence interval expanding up to ±€3.91 billion. An overall assessment of the innovation strategy effectiveness was conducted using a composite index. Table 9 presents the results of aggregating the individual components.

A lag in the effectiveness of innovation strategies is noticeable due to the CISI composite index for Europe (35.4) is 28% lower than the global value (49.1). The 28% gap between Europe's CISI (35.4) and the global benchmark (49.1) is not uniformly distributed across components: the RCI sub-index accounts for the largest share of the deficit (0.089 vs. 0.177), indicating that Europe's underperformance is rooted primarily in competitive positioning rather than in the efficiency of its research processes.

In particular, the largest contribution to this gap arrives from the RCI component (0.089 vs. 0.177), reflecting the relatively lower competitiveness of the European transport sector. The TER component shows a smaller difference (0.135 vs. 0.163), suggesting the relative effectiveness of R&D investment transformation into market outcomes. While the normalized CAGR component for the EU (0.043) is higher than the global value (0.033), the absolute growth rates remain lower.

Overall, these results highlight the systemic nature of EU's lagging behind global benchmarks in transport innovation efficiency. The uncovered underperformance finds its reflection in the lower R&D intensity, a high investment concentration within specific subsectors as well as slower market dynamics compared to countries in the Asia-Pacific region and North America.

5 Discussion

The high growth rate of the Smart Transport market (CAGR = 11.7%) confirms the acceleration of digitalization in transport systems; however, this figure alone does not explain the mechanisms driving this expansion. Unlike Zhang et al. [28], who attribute the growth primarily to technology integration at the infrastructure level, our findings suggest that market dynamics are structurally decoupled from R&D investment cycles - evidenced by the three-year lag captured in the TER coefficient. This distinction is critical: it implies that innovation management frameworks focused solely on increasing R&D expenditure, without addressing institutional absorption capacity, are insufficient. Curiel-Ramirez et al. [29] describe interdisciplinary integration as a prerequisite for smart electromobility ecosystems, and our results support this view - though they further indicate that interdisciplinarity alone cannot compensate for misaligned investment timelines.

The structural concentration index (SDI = 0.78) reveals that the automotive sector absorbs 70% of EU transport R&D, which constitutes a more severe imbalance than the literature has previously acknowledged. Mironova et al. [30] advocate for balancing exploitation of existing technologies with exploration of new directions; yet our data demonstrate that the EU innovation system has not operationalized this balance - the remaining three transport subsectors collectively receive only 30% of investment despite representing significant growth potential. This finding critically extends the argument of Serhieiev et al. [31] on innovation competencies: strategic competence in management is necessary but insufficient if investment allocation remains structurally skewed. The EU's €2.8 billion CEF commitment across 94 projects, highlighted by Yermachenko et al. [32] as evidence of institutional leadership, appears more modest when contextualized against the SDI value - suggesting that public funding is not yet redirecting private R&D away from automotive concentration.

The regional competitiveness asymmetry - Europe RCI 35.5 versus Asia-Pacific RCI 168.2 - challenges the implicit assumption in much of the innovation management literature that R&D expenditure translates proportionally into market position. Zhang et al. [33] demonstrate how geospatial optimization of IoT infrastructure can enhance competitive deployment; however, the RCI analysis presented here reveals that Europe's deficit is not primarily technological but structural: a 35% global market share maintained on only 12.8% of global R&D spending indicates dependence on legacy positioning rather than active innovation-driven competitiveness. Furthermore, Sarkar's [34] emphasis on cybersecurity as a systemic requirement for ITS deployment adds an often-overlooked cost dimension - one that may partially explain Europe's sluggish 1.7% ITS market growth, as security compliance requirements create additional barriers to rapid market scaling.

The non-linear nature of R&D-to-market transformation, captured by the TER reduction from 1.63 to 0.54 under a three-year lag, represents the most significant departure from conventional linear innovation models prevalent in the literature. While Sembada and Lenggoro [35] identify analogous diffusion delays in nanoparticle transport within biological systems, the parallel to technological adoption in transport lies in the concept of systemic resistance - both biological and institutional environments impose friction on diffusion regardless of the quality of the innovation itself. This reframing has direct managerial implications: the normalized TER of 4.53 confirms that the multiplier effect is real, but realizing it requires institutional mechanisms specifically designed to compress the lag period, rather than simply increasing R&D volumes.

These findings align with Prasetyo et al. [36], who demonstrate that AI integration in open innovation management accelerates R&D-to-market conversion — consistent with Smart Transport's CAGR of 11.7% outpacing traditional investment cycles. The SDI concentration risk resonates with Sá et al. [37], who identify portfolio diversification as critical for long-term competitiveness, while Hamdouna and Khmelyarchuk [38] confirm that the technological innovation yields sustainable advantage only when institutional frameworks actively bridge R&D intensity and market deployment. Yordanova et al. [39] further support the argument that reducing the TER lag requires not merely increased funding, but structural reforms balancing governance standardization with organizational flexibility.

The CISI composite index (EU: 35.4 vs. global: 49.1) synthesizes these findings into a diagnostic tool that, unlike single-indicator assessments common in prior studies, captures the multidimensional nature of innovation strategy effectiveness. The decomposition of the gap reveals that the RCI component contributes disproportionately to Europe's underperformance, while the TER component shows a comparatively smaller deficit - indicating that Europe's problem is less about converting research into outcomes and more about competing effectively in global markets. This nuance is absent from most existing benchmarking frameworks and represents a concrete methodological contribution: transport enterprises and policymakers can use CISI not merely to confirm underperformance, but to identify which specific strategic lever - competitiveness, intensity, efficiency, or growth - requires priority intervention.

5.1 Limitations

This study draws on the secondary data from official institutions and market agencies, and thus its potential to analyze the microdynamics of individual transport enterprises and the variability of management practices is limited. Furthermore, the analyzed indicators' time ranges are not fully aligned due to differences in the primary data availability. For example, EU transport R&D data encompass only 2019-2021, while the forecast estimates for the Smart Transportation market extend to 2034. This reflects variations in reporting cycles in Eurostat, industry analytical agencies and market databases. The formation of composite indices presupposes a stable institutional environment, though the transport sector is very sensitive to regulatory and geopolitical changes. Moreover, the analysis is calibrated for the EU, North America and Asia-Pacific regions, thus limiting the results' generalizability to other markets. In addition, the R&D investment data are not broken down by specific technologies, and the qualitative aspects of management creativity are not fully described by quantitative indicators.

5.2 Recommendations

1. It is advisable to reduce the investment concentration in road transport and reallocate resources to railway, urban and maritime innovations. This will help mitigate industry risks and improve the resilience and sustainability of the innovation system.
2. It is essential to strengthen innovation activity by increasing the share of R&D expenditures, in such a way minimizing the gap with global leaders and boosting transport sector's competitiveness.
3. It is expedient to accelerate the transformation of research into market-ready products by reducing time lags and facilitating closer collaboration between scientific institutions and transport operators.
4. It is recommended to promote interregional cooperation to facilitate the dissemination of effective management practices, support standardization and improve the return on innovative investments.
5. It is required to integrate creative management approaches and cultivate an experimentation culture as major conditions for adapting transport management to accelerated technological changes.

6 Conclusion

Summing up, in this study is highlighted the need for a multifaceted evaluation of transportation systems' innovative strategies in the context of digitalization. In this light, opportunities for higher efficiency from artificial intelligence arise, as well as from utilizing the Internet of Things and the big data. However, at the same time they make the evolution of management practices and the investment's conversion into research and development more complicated. The transformation efficiency coefficient of 0.54 confirms the complexity of converting research into market results, despite the multiplier effect of investments. Empirical analysis for the period 2019-2025 unveiled uneven dynamics across innovation segments. The smart transport market demonstrated an average annual growth rate of 11.7%, whereas the European segment of intelligent transport systems slowed down to 1.7%, as compared to the global growth rate of 5.1%. Likewise, the EU innovation intensity index (34.9) is still below the global benchmark (47.2). A considerable concentration of investments in the automotive sector was noticed, entailing structural risks associated with dependence on a single direction. Furthermore, the transformation efficiency coefficient (0.54) highlights the challenges of translating research investment into practical market results, despite the noted multiplier effect. The regional analysis revealed a significant asymmetry in terms of competitiveness between Europe and the Asia-Pacific region, thereby challenging the assumption of a homogeneous influence of innovative investments. The proposed methodology offers practical tools of diagnostics for assessing the effectiveness of innovation strategies and can serve as a foundation for international benchmarking and informed management decisions. Given the above, further endeavours should elaborate on long-term observation of management transformation and the development of predictive models that could evaluate the impact of managerial creativity on the rate of innovation diffusion. Future research should focus on the long-term monitoring of management transformations and the development of predictive models that evaluate how management creativity influences the pace of innovation diffusion across transport systems.

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Conflicts of interest

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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