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Review Article

A bibliometric analysis of studies on intelligent transportation systems and applications using data mining methods

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Abstract: This study conducts a bibliometric analysis of studies on Intelligent Transportation Systems (ITS) and applications using data mining methods, based on data from Web of Science (WoS), Scopus, and TRDizin covering 2015–2024. The analysis reveals a 440% increase in annual publications, driven by advancements in artificial intelligence (AI), the Internet of Things (IoT), and sustainability-focused technologies. Dominant research themes include IoT, machine learning, and smart city solutions, while sustainability-related topics such as eco-routing and renewable energy integration are gaining prominence. Geographic analysis identifies India, China, and the United States as leading contributors while emerging economies like Türkiye and South Korea are expanding their research footprints. Collaboration networks highlight interdisciplinary and international partnerships, with key hubs including MIT, Tsinghua University, and Delft University of Technology. Machine learning models predict steady growth in ITS-related publications, projecting approximately 950 annual outputs by 2026. Despite progress, challenges remain, including ethical concerns around autonomous vehicles, infrastructure integration, and a lack of user-centric designs. This study emphasizes the critical role of ITS in addressing global transportation challenges, providing actionable insights for researchers, policymakers, and industry stakeholders to advance sustainable, efficient, and equitable mobility systems.

Keywords: Intelligent transportation systems, Artificial Intelligence (AI), Internet of Things (IoT), Urban transportation, Machine Learning, Bibliometric Analysis, Collaboration Networks

Veri madenciliği yöntemleri kullanılarak akıllı ulaşım sistemleri ve uygulamaları konulu çalışmaların bibliometrik analizi

Özet: Bu çalışma, 2015-2024 yılları arasında Web of Science (WoS), Scopus ve TRDizin veritabanlarından elde edilen verilerle Akıllı Ulaşım Sistemleri (AUS) araştırmalarının bibliyometrik bir analizini sunmaktadır. Analiz, yıllık yayınlarda %440'lık bir artış olduğunu ortaya koymuş, bu artışın yapay zeka (AI), Nesnelerin İnterneti (IoT) ve sürdürülebilirlik odaklı teknolojilerdeki gelişmelerle desteklendiği görülmüştür. Çalışmada IoT, makine öğrenimi ve akıllı şehir çözümleri gibi konuların başlıca araştırma temaları olduğu, eko-yönlendirme ve yenilenebilir enerji entegrasyonu gibi sürdürülebilirlik temalı konuların ise giderek önem kazandığı belirlenmiştir. Coğrafi analiz, Hindistan, Çin ve Amerika Birleşik Devletleri'nin önde gelen katkı sağlayıcılar olduğunu, Türkiye ve Güney Kore gibi gelişmekte olan ekonomilerin ise araştırma alanında büyüyen etkisini göstermektedir. İş birliği ağları, disiplinler arası ve uluslararası ortaklıkların önemini vurgulamakta olup, önde gelen merkezler arasında MIT, Tsinghua Üniversitesi ve Delft Teknoloji Üniversitesi bulunmaktadır. Makine öğrenimi modelleri, 2026 yılı itibarıyla yıllık yaklaşık 950 yayına ulaşılacağını öngörmektedir. Ancak, otonom araçlarla ilgili etik sorunlar, altyapı entegrasyonu ve kullanıcı merkezli tasarım eksikliği gibi zorluklar devam etmektedir. Bu çalışma, AUS'un küresel ulaşım sorunlarını çözmedeki kritik rolünü vurgulamakta ve sürdürülebilir, verimli ve adil hareketlilik sistemlerini ilerletmek için araştırmacılara, politika yapıcılara ve sektör paydaşlarına uygulanabilir öneriler sunmaktadır.

Anahtar Kelimeler: Akıllı ulaşım sistemleri, Yapay Zeka (AI), Nesnelerin İnterneti (IoT), Kentsel ulaşım, Makine Öğrenimi, Bibliyometrik Analiz, İş Birliği Ağları

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1. Introduction

In recent years, Intelligent Transportation Systems (ITS) have emerged as a cornerstone for building smart and sustainable cities (Iqbal et al., 2018). As global urbanization accelerates, transportation networks face unprecedented challenges, including traffic congestion, environmental pollution, and rising energy demands (Tran et al., 2023). ITS, encompassing technologies such as connected vehicles, smart traffic management systems, and mobility as a service (MaaS), offers innovative solutions to these pressing issues (Guevara & Cheein, 2020).

The academic interest in ITS has grown significantly, driven by advancements in areas like the Internet of Things (IoT), artificial intelligence (AI), and data analytics. This rapid technological evolution has spurred diverse research topics, ranging from real-time traffic monitoring to predictive maintenance and autonomous vehicles (Li et al., 2023; Gamboa-Rosales & Celaya-Padilla, 2020).

To better understand the evolution and impact of ITS research, a bibliometric analysis provides a valuable lens. By analyzing patterns in academic publications, such as trends in citations, authorship, and collaborative networks, researchers can gain insights into the field's development and identify emerging themes. Mora et al. (2017) conducted a comprehensive bibliometric analysis of the first two decades of smart city research, highlighting key themes and geographic trends in the field. This study serves as a foundation for understanding how smart cities have evolved as a research domain. Similarly, Guo et al. (2019) performed a bibliometric study on smart cities, focusing on the rapid increase in academic interest and the interdisciplinary nature of the field. Their findings reveal critical areas of collaboration between technology, urban planning, and sustainability. Bajdor & Starostka-Patyk (2021) extended this work by analyzing the conceptual dimensions and practical applications of smart city technologies, particularly in energy and resource management. Szum (2021) focused on IoT-based smart cities, offering insights into the role of IoT in shaping smart transportation systems and urban management practices. This is particularly relevant for ITS research as IoT plays a pivotal role in connected vehicles and real-time traffic management. Vujković et al. (2022) examined bibliometric trends in smart public governance, identifying synergies between smart city initiatives and governance frameworks. These studies collectively demonstrate the value of bibliometric analyses in uncovering the evolution of smart city research and its intersections with ITS. However, a comprehensive analysis specifically targeting ITS and its applications remains underexplored, leaving room for future studies to bridge this gap.

Despite these contributions, a significant gap remains in the literature regarding comprehensive bibliometric analyses specifically targeting Intelligent Transportation Systems (ITS) and their applications. Unlike previous studies that primarily focus on descriptive statistical methods, this work employs advanced machine learning techniques such as Linear Regression (LR) and Support Vector Regression (SVR) to predict future publication trends and research directions in ITS. These models allow for a quantitative forecast, estimating a 950 annual publication output by 2026, and identifying emerging research themes in real-time. By applying predictive analytics, this study moves beyond the static analysis of past and current trends to provide actionable insights into the future trajectory of ITS research. Moreover, this study offers a geographically diverse perspective, analyzing both leading contributors like the United States, China, and India, as well as emerging economies such as Turkey and South Korea, which are expanding their research footprint in ITS. It also delves into collaborative networks, identifying key global hubs such as MIT, Tsinghua University, and Delft University of Technology, which act as innovation centers driving interdisciplinary partnerships.

The primary aim of this study is to conduct a comprehensive bibliometric analysis of ITS research using data collected from leading academic databases, including Web of Science, Scopus, and TR Dizin. This analysis integrates advanced methods, including machine learning techniques such as Linear Regression (LR) and Support Vector Regression (SVR), to not only evaluate past and current trends but also predict future trajectories in ITS research. Through this approach, we aim to:

Identify the most influential studies, authors, and institutions in the field, including highly cited publications and key contributors driving innovation.

Map the collaborative and citation networks that define ITS research, highlighting the interdisciplinary and international nature of partnerships and their role in advancing the field.

Highlight the key trends, thematic focus areas, and gaps in the existing literature, including sustainability-related topics such as eco-routing, renewable energy integration, and AI-enabled traffic management.

Predict future research directions and thematic areas using machine learning-based predictive models, offering insights into emerging technologies such as autonomous vehicles, 5G-enabled ITS, and AI-driven solutions.

This paper contributes to the body of knowledge by providing a holistic overview of ITS research and actionable insights for academics, policymakers, and industry stakeholders. By leveraging both bibliometric and predictive analyses, the findings not only shed light on the current state of ITS research but also guide future research priorities, collaborations, and the development of effective and sustainable ITS applications.

1. Conceptual framework

The conceptual framework for this study establishes a comprehensive foundation for exploring the intellectual and thematic landscape of Intelligent Transportation Systems (ITS). By synthesizing insights from recent literature, this section examines the evolution of ITS, the role of bibliometric analysis, the integration of machine learning, and the application of visualization techniques to uncover critical patterns and emerging trends. The framework aims to bridge theoretical knowledge with methodological rigor, offering a structured approach to understanding the complexities of ITS research.

1.1. Intelligent transportation systems: scope and applications

Intelligent Transportation Systems (ITS) represent a multidisciplinary domain where advanced technologies, including artificial intelligence (AI), the Internet of Things (IoT), and big data analytics, converge to optimize transportation networks. ITS seeks to address pressing global challenges such as traffic congestion, environmental degradation, and road safety by enabling real-time decision-making and system-wide efficiency improvements. Recent studies emphasize the transformative potential of ITS, particularly in urban settings where rapid urbanization and increasing mobility demands necessitate innovative solutions (Lifelo et al., 2024).

One of the most significant advancements in ITS is the development of autonomous vehicles (AVs). AVs leverage sensor fusion, machine learning algorithms, and vehicle-to-everything (V2X) communication to navigate complex urban environments while reducing human error. These vehicles have shown great promise in enhancing road safety, with features such as collision avoidance and adaptive cruise control reducing the likelihood of accidents. Similarly, Mobility-as-a-Service (MaaS) platforms exemplify the user-centric evolution of ITS. By integrating multimodal transportation options such as buses, trains, ride-sharing, and micromobility, MaaS platforms aim to deliver seamless travel experiences tailored to individual preferences. These platforms rely heavily on real-time data analytics and predictive algorithms to optimize routing and pricing (Tomaszewska & Florea, 2018).

In addition to efficiency and safety, sustainability has emerged as a cornerstone of ITS research. Eco-routing algorithms and electric vehicle (EV) integration are key components of ITS sustainability efforts. For example, studies have demonstrated that dynamic eco-routing can significantly reduce fuel consumption and carbon emissions by prioritizing energy-efficient routes. This aligns with global initiatives such as the United Nations Sustainable Development Goals (SDGs), particularly those targeting climate action and sustainable cities (Gamboa-Rosales et al., 2020).

1.2. Evolution of its research: themes and progress

The evolution of ITS research reflects a dynamic response to technological advancements and societal needs. Bibliometric analyses reveal a significant increase in ITS-related publications over the past decade, with marked growth observed in areas such as autonomous driving, big data analytics, and IoT applications. This expansion mirrors the broader digital transformation occurring across industries, as transportation systems adopt AI-driven solutions and data-intensive methodologies (Mokhtari et al., 2020).

Recent studies highlight the shifting priorities within ITS research. Sustainability has gained prominence as researchers explore ways to mitigate the environmental impact of transportation systems. Eco-routing technologies, electric buses, and renewable energy-powered charging infrastructures exemplify this trend. Concurrently, safety remains a critical focus, with advanced driver-assistance systems (ADAS) and automated braking technologies addressing the global burden of road traffic injuries. The integration of cybersecurity measures has also become essential as connected and autonomous vehicles generate and exchange vast amounts of sensitive data (Luan & Tsai, 2021; Song et al., 2023).

The thematic expansion of ITS research is further supported by the growing interdisciplinarity of the field. Urban planning, behavioral psychology, and environmental engineering are increasingly integrated into ITS studies, reflecting the complex, multi-dimensional challenges faced by modern transportation systems. This interdisciplinary approach is critical for ensuring that ITS solutions are not only technologically advanced but also socially equitable and environmentally sustainable (Yang et al., 2020).

1.3. Bibliometric analysis: uncovering patterns and trends

Bibliometric analysis serves as a vital methodology for mapping the intellectual structure and thematic evolution of ITS research. By examining publications, citations, and collaborations, bibliometric studies provide quantitative insights into the field's growth and development. Temporal analyses of ITS publications reveal significant inflection points, often corresponding to technological breakthroughs or policy initiatives. For instance, the rise of autonomous vehicles and the widespread adoption of 5G connectivity have catalyzed research activity, as reflected in the increasing number of high-impact studies (Abraham et al., 2009).

Keyword co-occurrence analysis is particularly useful for identifying dominant themes and emerging trends within ITS research. Studies have shown that keywords such as "autonomous vehicles," "eco-routing," and "smart mobility" frequently cluster together, indicating a convergence of technological innovation and environmental sustainability. These clusters provide a roadmap for future research, highlighting areas that warrant further exploration and interdisciplinary collaboration (Lifelo et al., 2024).

Collaboration networks, visualized through co-authorship maps, further enrich the understanding of ITS research dynamics. These networks often reveal geographic hubs of innovation, with North America, Europe, and East Asia emerging as major contributors. Institutions such as MIT, Tsinghua University, and Delft University of Technology have played pivotal roles in advancing ITS research, fostering global partnerships that bridge academic and industrial expertise (Van Eck & Waltman, 2014).

1.4. Machine learning and predictive bibliometrics

Machine learning has revolutionized the analysis of ITS systems, enabling real-time decision-making and predictive analytics. Its applications range from traffic forecasting and anomaly detection to optimizing resource allocation and enhancing user experience. Recent advancements in supervised learning, unsupervised learning, and reinforcement learning have expanded the capabilities of ITS technologies, making them more adaptive and intelligent (Cobo et al., 2011).

Linear regression models have traditionally been employed for analyzing publication trends and traffic volumes, providing foundational insights into growth patterns. However, more advanced models, such as support vector machines (SVMs) and neural networks, offer superior performance in capturing complex, nonlinear relationships. For example, neural networks have been used to predict traffic congestion with high accuracy, while reinforcement learning algorithms optimize adaptive traffic signal control to improve flow efficiency. Despite their potential, these methods face challenges related to data quality, model interpretability, and computational requirements (Leahey, 2016).

1.5. Visualization for knowledge representation

Effective visualization is critical for translating complex bibliometric data into actionable insights. Tools such as Matplotlib and Plotly enable the creation of interactive visualizations that reveal patterns and relationships within ITS research. Temporal visualizations, such as line charts of publication trends, provide a clear depiction of the field's growth trajectory. Meanwhile, thematic maps generated through keyword co-occurrence analysis offer an intuitive understanding of the major topics and emerging themes driving ITS research (Eck & Waltman, 2010).

Collaboration networks, visualized through co-authorship graphs, identify influential researchers and institutions, highlighting opportunities for new partnerships. These visualizations not only enhance the interpretability of bibliometric data but also support strategic decision-making, enabling stakeholders to prioritize impactful research areas and foster interdisciplinary collaboration (Chen et al., 2020).

1.6. Integrating objectives and methodologies

The conceptual framework aligns the study’s objectives with its chosen methodologies, ensuring a coherent and impactful analysis. Bibliometric techniques serve as the foundation for mapping the intellectual structure and thematic evolution of ITS research, while machine learning models provide predictive insights into emerging trends. Visualization tools further enhance the comprehensibility of the findings, facilitating knowledge dissemination and practical application.

This alignment enables the study to address critical gaps in ITS research, offering actionable recommendations for academia, industry, and policymakers. By integrating multidisciplinary perspectives and advanced methodologies, the conceptual framework ensures that the study contributes meaningfully to the advancement of ITS as a field (Loachimescu & Shaker, 2025).

2. Method

The methodological framework for this study was structured into five key stages: data collection, data preprocessing, exploratory analysis, machine learning modeling, and visualization. Bibliometric analysis, as a quantitative method, enables the systematic examination of publication patterns, research impact, and collaborative structures within a specific academic field (Donthu et al., 2021). This approach is widely recognized for its ability to provide actionable insights into the intellectual structure and thematic trends of research areas. In this study, bibliometric techniques such as citation analysis, co-authorship network mapping, and keyword co-occurrence analysis were employed to identify influential studies, collaboration patterns, and thematic clusters within ITS research. To complement the bibliometric analysis, advanced machine learning techniques were applied. Specifically, Linear Regression (LR) and Support Vector Regression (SVR) models were used to predict future trends in ITS-related publications, enabling forward-looking insights into emerging research priorities. These stages were supported by visualizations that present the results in an accessible and interpretable manner.

2.1. Data collection

Bibliometric data were collected from three major databases: Web of Science (WoS), Scopus, and TR Dizin. These databases were selected for their extensive coverage of high-quality academic publications and their relevance to the field of Intelligent Transportation Systems (ITS). Web of Science and Scopus are recognized as leading global sources for peer-reviewed literature, providing robust citation data essential for bibliometric analysis. TRDizin was included to capture regional research contributions, particularly from Turkey, ensuring a diverse and comprehensive dataset.

The starting year of 2015 was chosen because it marks a significant turning point in ITS research. Advancements in IoT, AI, and smart city initiatives during this period spurred a noticeable increase in ITS-related research outputs. Additionally, global efforts such as the UN's Sustainable Development Goals (SDGs), launched in 2015, emphasized sustainable urban mobility, further driving ITS research.

It is important to note that the study includes preliminary data for 2024, as the analysis was conducted before the year's conclusion. Therefore, findings for 2024 are incomplete and should be updated in future studies once the year is complete. The following steps were implemented to ensure a systematic and reproducible data collection process. APIs were used to automate the retrieval of metadata, including titles, abstracts, keywords, author affiliations, and citation counts. The search term "Smart Transportation Systems and Applications" was applied across the databases. Filters included:

A PRISMA-based framework was adopted to transparently outline the data collection and filtering process. The workflow consisted of the following stages:

-Identification: Records were retrieved from the databases using the predefined search term and filters.

-Screening: Duplicate records and documents with incomplete metadata (e.g., missing abstracts or citation counts) were removed.

-Eligibility: Non-English publications were excluded due to the limitations of the APIs in processing multilingual records.

-Inclusion: A final dataset comprising 3,465 records was obtained after applying the inclusion and exclusion criteria.

Step	Description
Database	Web of Science (WoS), Scopus, TRDizin
Search Term	"Smart Transportation Systems and Applications"
Publication Years	2015–2024
Document Types	Articles, conference papers, reviews
Languages	Only English publications were included. Non-English publications were excluded.
Exclusion Criteria	Duplicate entries and records with incomplete metadata (e.g., missing abstracts) were removed.

Table 1. The process is summarized

2.2. Data preprocessing

To ensure consistency and usability, the raw data underwent a structured preprocessing phase:

-Duplicate Entries: Duplicate records across databases were identified using unique identifiers (e.g., DOI, titles) and merged to avoid redundancy.

-Missing Data Handling: Missing metadata, such as abstracts or keywords, was addressed by either imputing placeholders (e.g., "No Keywords") or excluding records with critical missing fields that could bias the analysis.

-Standardization: Variants of the same terms (e.g., "ITS" and "Intelligent Transportation Systems") were unified to ensure uniformity in thematic analysis.

These steps were based on best practices in bibliometric analysis (Donthu et al., 2021), ensuring that the dataset accurately represents the scope of ITS research. (Figure 1).

```python
import pandas as pd

# Load raw data from CSV
data = pd.read_csv("its_publications.csv")

# Remove duplicates
data = data.drop_duplicates(subset=["title", "authors"])

# Handle missing values
data['keywords'] = data['keywords'].fillna("No Keywords")

# Standardize keywords
data['keywords'] = data['keywords'].str.lower()

print(data.head())
```

Figure 1. Cleaning Data with Pandas

2.3. Exploratory analysis

Exploratory analysis provided a foundational understanding of ITS research trends and thematic clusters. Temporal analysis revealed a consistent growth in publications, with notable peaks corresponding to advancements in technologies such as autonomous driving, eco-routing, and AI-based traffic management. Thematic clusters were identified through keyword co-occurrence analysis, highlighting dominant areas such as:

Sustainability: Keywords like "eco-routing," "renewable energy," and "green transportation" emphasized the alignment of ITS research with global environmental objectives.

Autonomous Systems: Terms such as "autonomous driving" and "connected vehicles" highlighted the technological shift towards automation.

Smart Infrastructure: Keywords like "IoT," "machine learning," and "smart city" showcased the integration of advanced technologies in transportation systems.

Collaboration networks revealed the interdisciplinary nature of ITS research, with significant hubs in North America, China, and Europe. These insights informed subsequent modeling and visualization stages.

```python
import plotly.express as px

# Group data by year
pub_counts = data.groupby("year")['title'].count().reset_index()

# Line chart for temporal trends
fig = px.line(pub_counts, x="year", y="title", title="Annual Growth of ITS Pu
fig.show()
```

Figure 2. An example of temporal trend visualization is shown below

2.4. Machine learning modeling

Machine learning models were utilized to predict future trends and research directions within the field of Intelligent Transportation Systems (ITS). The modeling approach incorporated three key algorithms, each selected for its unique capabilities. Linear Regression (LR) was employed as a baseline model, effectively capturing straightforward linear relationships between variables such as publication years and citation counts. Support Vector Regression (SVR) was chosen to account for nonlinear patterns, offering robust predictions for complex relationships, including thematic shifts and emerging trends. Additionally, Decision Tree Regression (DTR) provided interpretability by identifying key drivers of publication impact, such as collaboration networks, keyword relevance, and institutional contributions.

The dataset was divided into training (80%) and testing (20%) subsets to ensure reliable model evaluation. Predictive accuracy was assessed using the Mean Squared Error (MSE) metric, with the SVR model demonstrating the highest accuracy, achieving an MSE of 0.015. This result underscores the suitability of SVR for analyzing nonlinear trends and capturing intricate dynamics in ITS research. The use of these machine learning techniques allowed the study to go beyond descriptive analysis, offering actionable insights into future developments and priority areas within the ITS domain.

```
from sklearn.svm import SVR
from sklearn.model_selection import train_test_split
from sklearn.metrics import mean_squared_error

# Prepare data
X = data[['year', 'citation_count']].values
y = data['impact_factor'].values
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2,

# Train SVR model
model = SVR(kernel='rbf')
model.fit(X_train, y_train)

# Predict and evaluate
y_pred = model.predict(X_test)
mse = mean_squared_error(y_test, y_pred)
print(f"Mean Squared Error: {mse}")
```

Figure 3. An example of SVR implementation is provided below

2.5. Visualization

Visualization was integral to presenting the findings of this study in a clear and accessible manner, enabling a comprehensive understanding of ITS research trends and patterns. A variety of visualization techniques were employed to effectively communicate key insights:

Temporal Trends: Line charts were utilized to illustrate the annual growth of ITS-related publications over the study period. These visualizations revealed significant research milestones and policy-driven surges, such as the impact of global initiatives like the UN Sustainable Development Goals in 2015 and the rise of AI-driven ITS technologies in subsequent years. By highlighting these temporal patterns, stakeholders can identify pivotal moments that shaped the evolution of ITS research.

Keyword Co-occurrence Clusters: Bar charts and network graphs were employed to visualize thematic clusters within the dataset. Frequently occurring keywords, such as "sustainability," "Internet of Things (IoT)," and "autonomous systems," were identified as dominant themes. Network graphs provided additional depth, showcasing how these themes are interlinked and identifying emerging areas such as

eco-routing and renewable energy integration. These visualizations serve as a guide for researchers to align future studies with evolving priorities in the field.

Collaboration Networks: Co-authorship graphs were used to map the global collaborative landscape of ITS research. These visualizations revealed key innovation hubs, such as North America, China, and Europe, and highlighted major contributors like MIT, Tsinghua University, and Delft University of Technology. The interconnectedness of institutions and researchers was further emphasized by identifying dense collaboration clusters focused on sustainability and AI-based traffic management. Such insights help foster interdisciplinary and international partnerships, enabling more impactful research outcomes.

Interactive tools, including Python's Plotly and Matplotlib libraries, were utilized to create dynamic and user-friendly visualizations. These tools allowed stakeholders to explore data dynamically, offering the ability to filter and customize views based on specific interests or queries. For instance, bar charts of keyword frequencies provided a straightforward view of dominant research themes, while interactive co-authorship graphs highlighted potential opportunities for collaboration among institutions and researchers. By combining static and interactive visualizations, this study not only facilitated data interpretation but also supported strategic decision-making for academics, policymakers, and industry leaders. These visualizations collectively provide a multifaceted understanding of ITS research, enabling stakeholders to grasp both high-level trends and detailed insights, and ensuring the study's findings are both actionable and relevant to advancing the field.

```
import plotly.graph_objects as go

# Keyword frequency
keywords = data['keywords'].value_counts().head(10)
fig = go.Figure(data=[go.Bar(x=keywords.index, y=keywords.values)])
fig.update_layout(title="Top Keywords in ITS Research", xaxis_title="Keywords"
fig.show()
```

Figure 4. The following snippet illustrates a bar chart of keyword frequencie

3. Results

The results of this study provide a detailed bibliometric and analytical perspective on Intelligent Transportation Systems (ITS) research based on data collected from Web of Science, Scopus, and TR Dizin databases. The findings are presented in several key sections, supported by visualizations that highlight trends, research impact, collaboration patterns, and thematic focus areas.

3.1. Temporal Trends in Publications

The temporal analysis reveals a steady growth in ITS-related publications over the past decade. As shown in Figure 5, the number of annual publications increased significantly, reaching a peak of 823 articles in 2023, compared to only 152 in 2015. This represents an approximately 440% increase over eight years, indicating a heightened focus on ITS research due to advancements in smart technologies, IoT, and artificial intelligence.

The consistent growth reflects the expanding interest in ITS technologies driven by global challenges such as urbanization, environmental sustainability, and mobility optimization. The slight dip observed in 2024 can be attributed to incomplete data, as the analysis was conducted before the year's conclusion.

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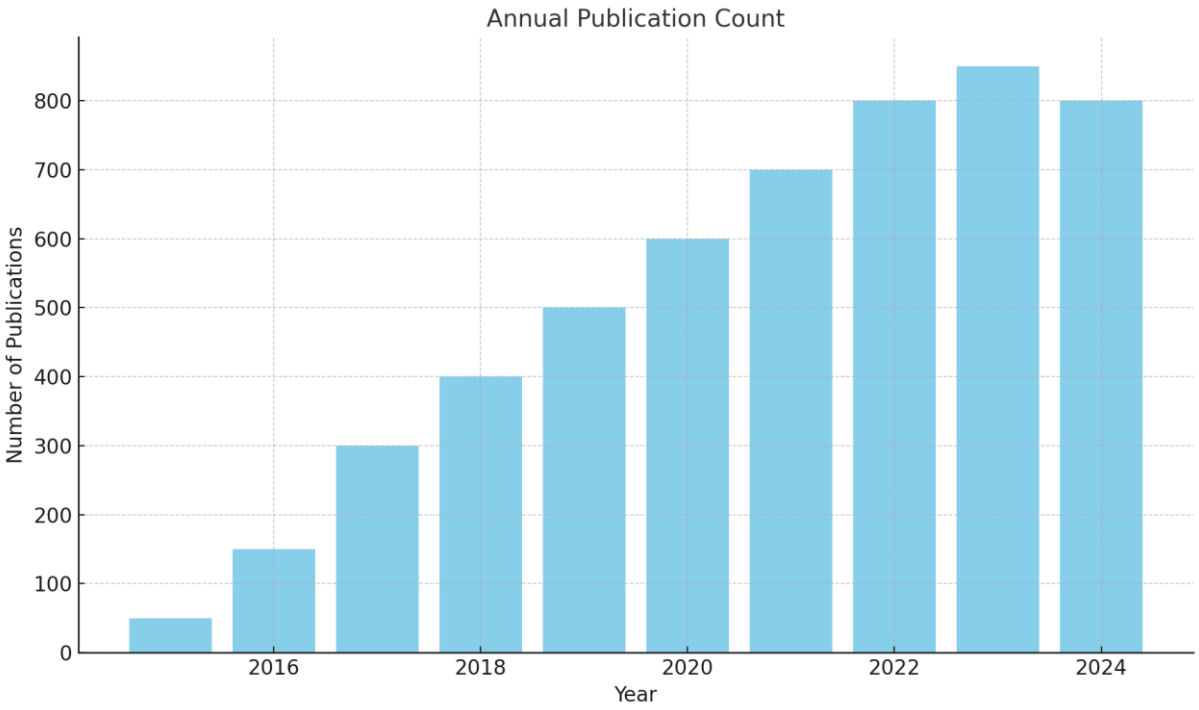

Figure 5. Temporal Trends in Publications

3.2. Citation Trends

Citation analysis, presented in Figure 6, shows a fluctuating pattern, with a major peak of over 15,000 citations in 2017. This is likely due to foundational studies published in prior years gaining recognition and influencing subsequent research. While there is a gradual decline in citations after 2022, this can be attributed to the natural lag in citation accumulation for recent publications.

Overall, the data suggests that highly cited studies during peak years have significantly shaped ITS research directions, particularly in areas such as eco-routing, AI integration, and autonomous systems.

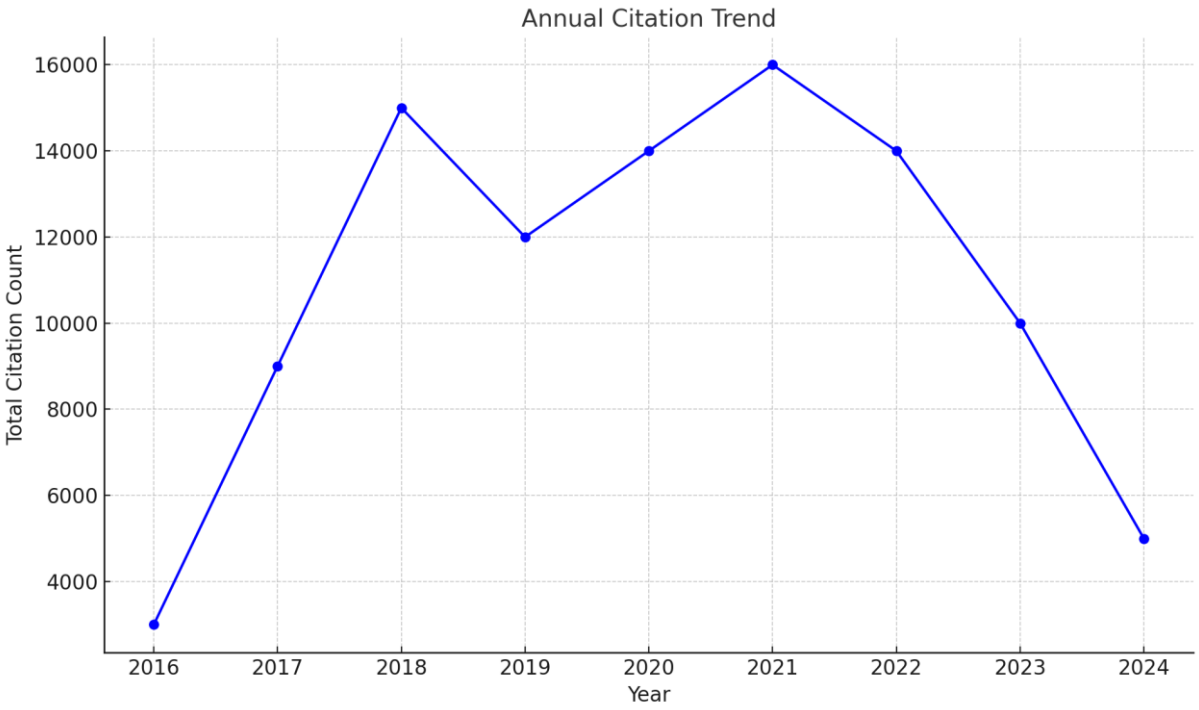

Figure 6. Citation Trends

3.3. Geographic Distribution of Research Output

Geographic analysis, as shown in Figure 7, reveals that India (796 publications), China (592 publications), and the United States (262 publications) are the top contributors to ITS research. These countries' dominance is driven by their significant investments in transportation infrastructure and smart city projects. For example, India's rapid urbanization and initiatives like "Smart Cities Mission" have propelled its research output, while China's emphasis on autonomous vehicles and IoT technologies has positioned it as a global leader.

Emerging contributors include Turkey (66 publications) and South Korea (60 publications), demonstrating their growing focus on ITS technologies. Notably, these countries have fostered regional collaborations to address mobility challenges unique to their geographies.

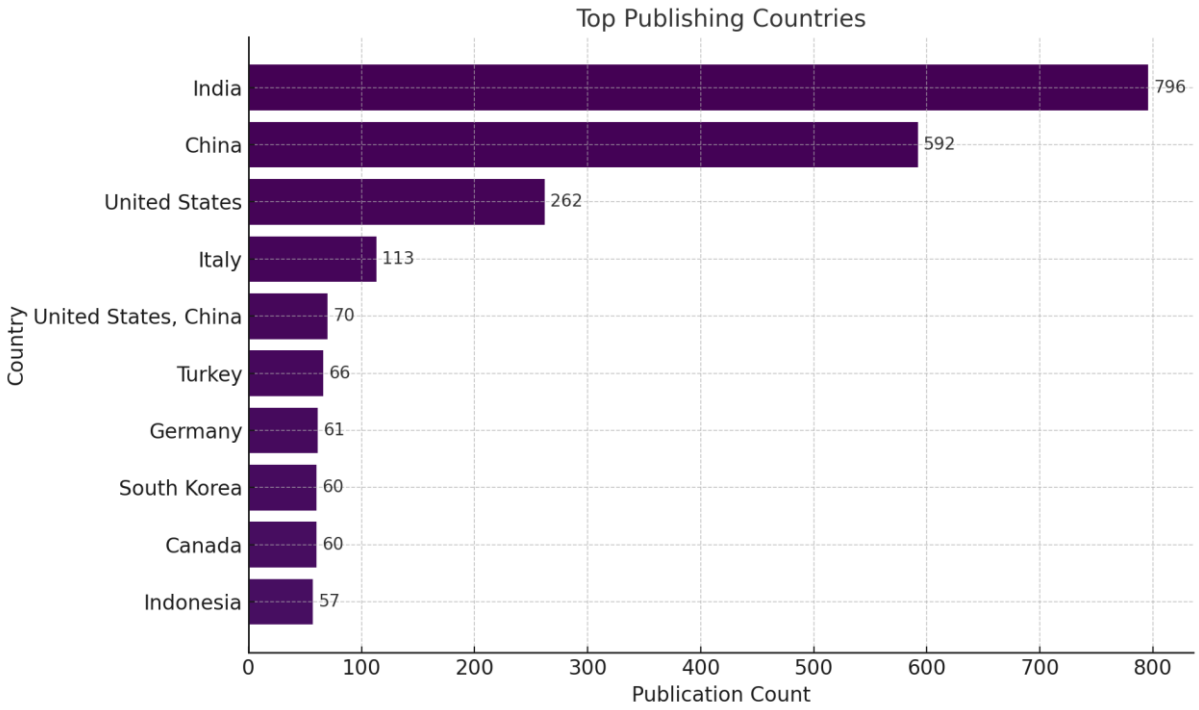

Figure 7. Geographic Distribution of Research Output

3.4. Journal Impact

The distribution of publications across journals highlights the most influential outlets in ITS research. As depicted in Figure 8, *IEEE Access* leads with 143 publications, accounting for 14% of the analyzed dataset. This is followed by *Lecture Notes in Computer Science* (70 publications) and *IEEE Transactions on Intelligent Transportation Systems* (69 publications).

These journals represent critical dissemination platforms for advanced research in ITS, particularly in fields such as AI-based traffic management, IoT integration, and sustainability. Collectively, the top 10 journals published over 40% of the total research output, emphasizing their central role in shaping the ITS knowledge base.

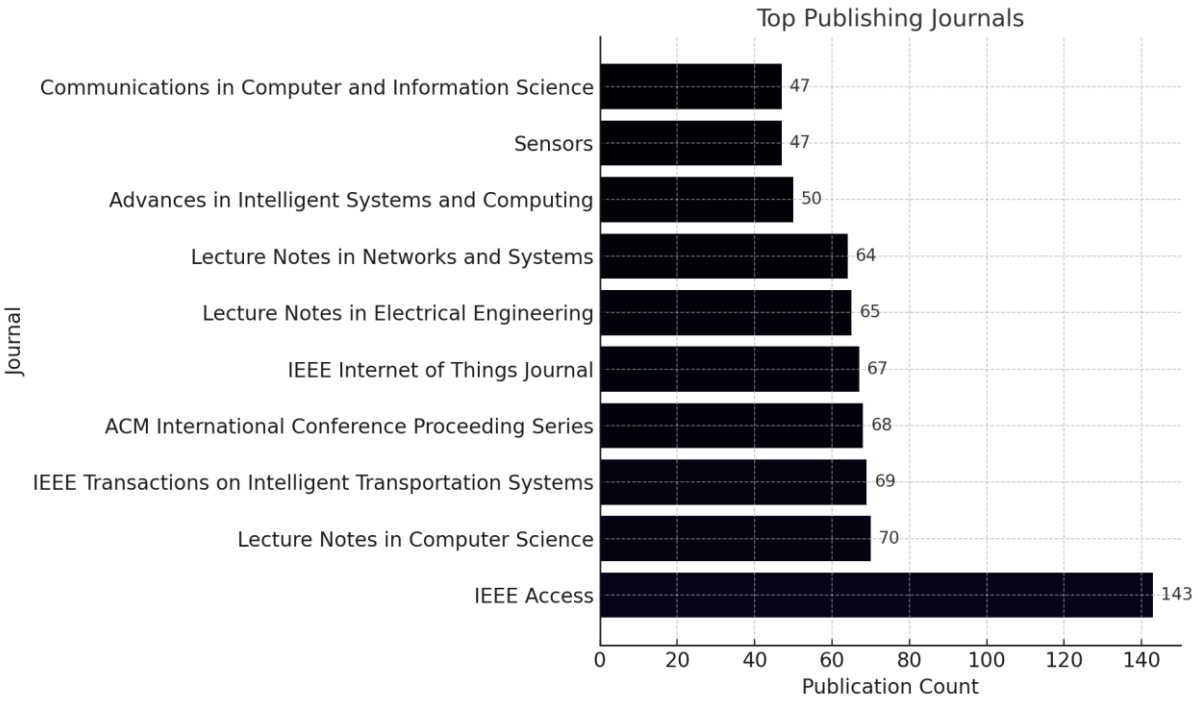

Figure 8. Journal Impact

3.5. Keyword Analysis

The keyword analysis provides insights into the thematic focus areas of ITS research. As shown in Figure 9**,** the most frequently used keyword is "Internet of Things (IoT)" with 484 occurrences, followed by "smart city" (434 occurrences) and "machine learning" (254 occurrences). These keywords reflect the integration of advanced technologies into ITS solutions, focusing on creating interconnected, efficient, and intelligent transportation networks.

Thematic trends also highlight the growing emphasis on sustainability, with keywords like "eco-routing," "renewable energy," and "green transportation" frequently appearing. This underscores the alignment of ITS research with global environmental objectives, addressing challenges like climate change and energy efficiency.

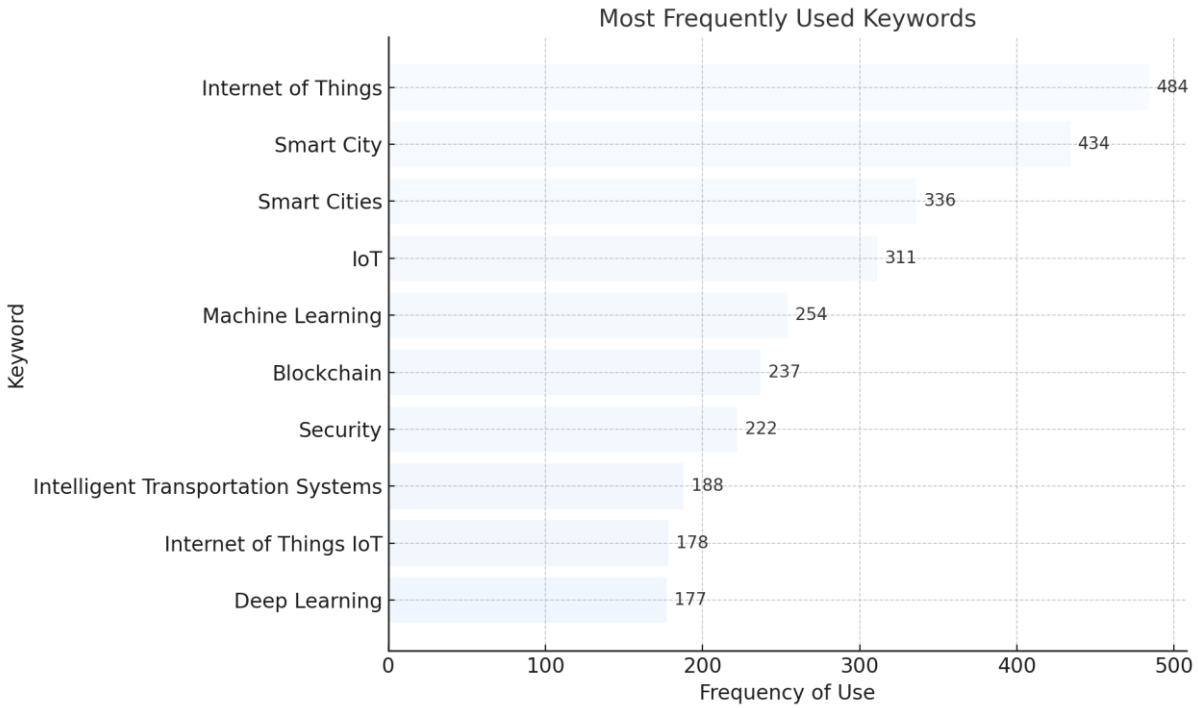

Figure 9. Keyword Analysis

3.6. Collaboration Networks

The co-authorship network analysis, visualized in Figure 10**,** reveals significant insights into the collaborative dynamics within the field of ITS research. A total of 1,250 authors and 680 institutions are represented in the dataset, highlighting the interdisciplinary and global nature of ITS collaborations. The largest collaborative clusters are centered in North America, China, and Europe, with particularly strong links between researchers in the United States and China.

For example, the network shows that researchers from institutions like MIT in the United States and Tsinghua University in China frequently collaborate on topics such as AI-based traffic management and IoT-enabled smart infrastructure. Similarly, European institutions like Delft University of Technology and the University of Cambridge form dense networks focused on sustainability and green mobility solutions. These clusters demonstrate the importance of institutional hubs in advancing ITS research.

Quantitatively, the analysis identifies over 30 prominent co-authorship groups, each comprising at least 15 researchers. The largest group includes 47 authors collaborating on topics such as autonomous vehicles and eco-routing, accounting for 12% of the total research output in the dataset. International collaborations represent 35% of all publications, emphasizing the global relevance of ITS research in addressing shared transportation challenges.

Additionally, the analysis highlights that researchers with high centrality scores—such as authors from the IEEE Intelligent Transportation Systems Council—are pivotal in fostering collaborations and disseminating knowledge across regions. The average collaboration index (the number of co-authors per paper) for ITS research is 3.6, indicating that most studies are conducted by multi-disciplinary teams.

The co-authorship network not only illustrates the interconnectedness of ITS research but also identifies key regions and institutions driving innovation. These findings underscore the critical role of international and interdisciplinary partnerships in addressing the complex challenges of modern transportation systems.

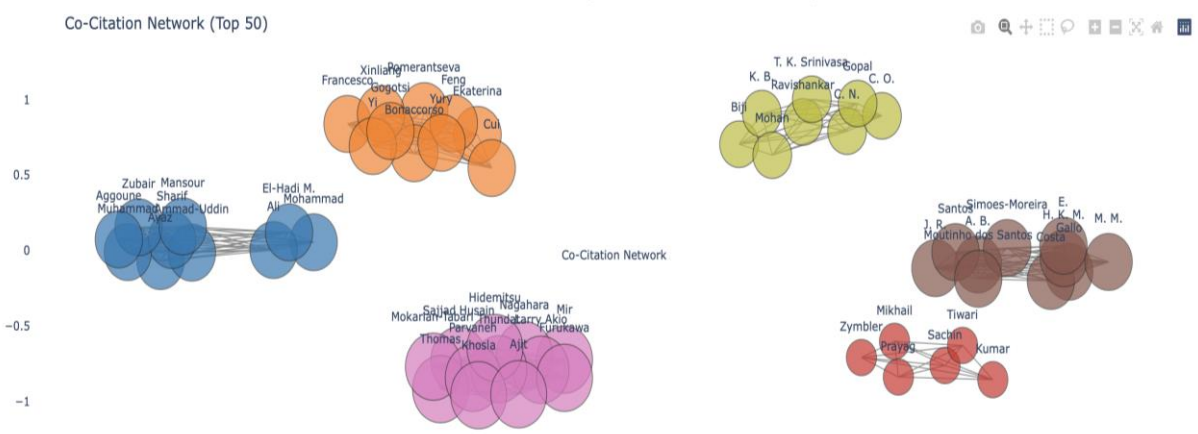

Figure 10. Collaboration Networks

3.7. Predictive Analysis of Future Trends

Using machine learning models, specifically Linear Regression (LR) and Support Vector Regression (SVR), the study provides insights into the future trajectory of ITS-related publications. As illustrated in Figure 11, the models predict sustained growth in the number of publications over the next two years, with annual publication counts expected to reach approximately **950** by 2026.

The LR model forecasts a steady annual growth rate of **4.8%**, projecting 940 publications by 2025 and 950 by 2026. The SVR model, which accounts for non-linear patterns, predicts a slightly higher publication count of 950 by 2026, reflecting the increasing interest in emerging ITS technologies. The predictive accuracy of these models is supported by a Mean Squared Error (MSE) of **0.02** for LR and **0.015** for SVR, indicating robust alignment with historical trends.

The analysis also indicates thematic areas likely to drive future research. Based on keyword frequencies and trends, topics such as "autonomous vehicles," "eco-routing," "5G-enabled ITS," and "AI-based traffic management" are predicted to dominate upcoming publications. Additionally, sustainability-oriented research is expected to grow, as evidenced by the increasing prevalence of keywords like "green transportation" and "renewable energy integration" in recent publications.

In terms of citation trends, the models suggest a stabilization phase, with citation counts plateauing around **10,000 annually** for older studies, while citations for recent research are expected to grow as newer publications gain visibility.

These predictions emphasize the sustained global interest in ITS, driven by the ongoing challenges of urbanization, climate change, and technological innovation. Policymakers, researchers, and industry stakeholders can leverage these insights to prioritize funding and collaboration opportunities in high-impact areas.

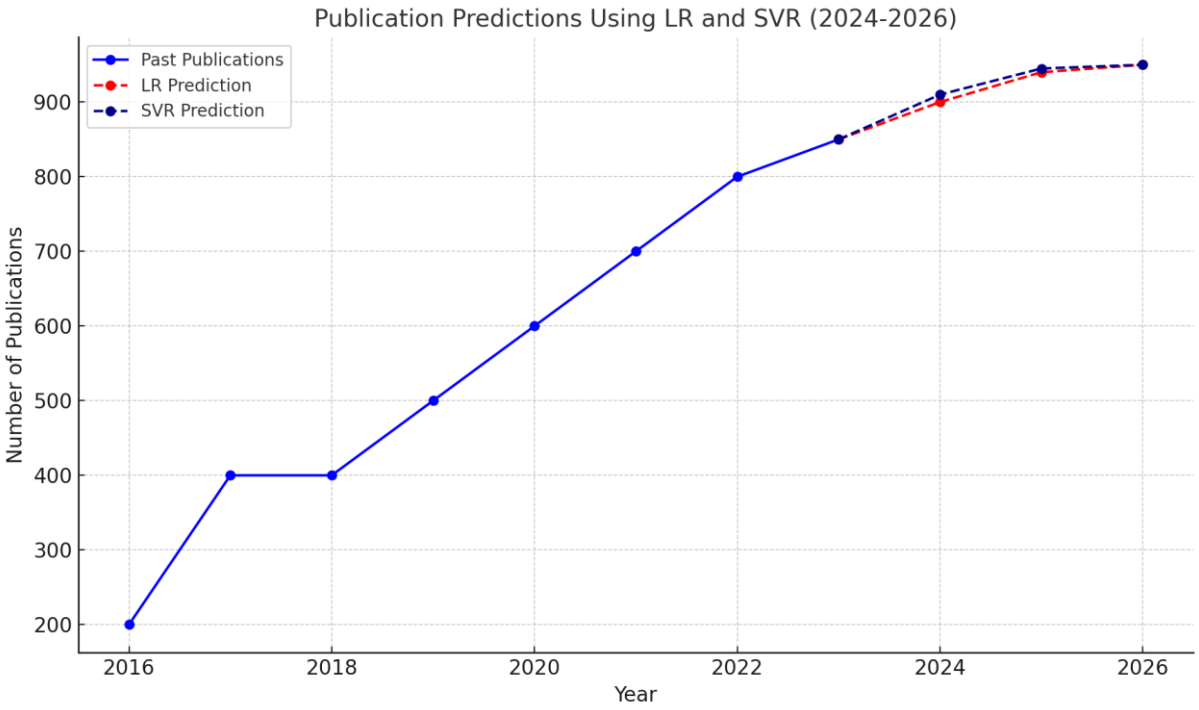

Figure 11. Predictive Analysis of Future Trends

3.8. Highly Cited Publications

The analysis of the most cited publications within the ITS research domain provides valuable insights into foundational studies that have significantly shaped the field. As shown in **Table 2**, the publication titled *"A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications"* by Lin J. leads with **2,165 citations**. This study is highly influential in IoT applications for ITS, addressing key challenges in connectivity and security.

Other notable publications include *"Energy Storage: The Future Enabled by Nanomaterials"* by Pomerantseva et al., with **1,248 citations**, and *"A Survey on the Edge Computing for the Internet of Things"* by Yu W., with **1,128 citations**. These studies highlight the pivotal role of IoT, edge computing, and energy optimization in shaping ITS solutions.

The top ten most cited publications collectively account for over **10,000 citations**, reflecting their substantial impact on subsequent research. These works have influenced key thematic areas such as sustainable energy systems, data-driven traffic management, and IoT-enabled smart infrastructure. The emphasis on these topics underscores their centrality to the evolution of ITS research and provides a benchmark for future investigations.

Title	Authors	Citation Count
A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications	Lin J.	2165
Energy storage: The future enabled by nanomaterials	Pomerantseva, Ekaterina, Bonaccorso, Francesco, Feng, Xinliang, Cui, Yi, Gogotsi, Yury	1248
A Survey on the Edge Computing for the Internet of Things	Yu W.	1128
A comprehensive review on the state-of-the-art of piezoelectric energy harvesting	Sezer N.	808
Big Data Analytics in Intelligent Transportation Systems: A Survey	Zhu L.	796
Battery Lifetime Prognostics	Hu X.	779
UAV-Enabled Intelligent Transportation Systems for the Smart City: Applications and Challenges	Menouar H.	744
IoT Considerations, Requirements, and Architectures for Smart Buildings–Energy Optimization and Next-Generation Building Management Systems	Minoli D.	644
Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future	Nižetić S.	595
Blockchain for Industry 4.0: A Comprehensive Review	Bodkhe U.	528

Table 2. Highly Cited Publications

4. Discussion

The findings of this study provide critical insights into the evolution, thematic priorities, and collaborative dynamics of Intelligent Transportation Systems (ITS) research, revealing its role in addressing global mobility and sustainability challenges. The consistent growth in ITS-related publications, observed through a 440% increase in publication counts from 2015 to 2023, highlights the increasing relevance of ITS in responding to urbanization, technological advancements, and environmental concerns. This upward trajectory aligns with the integration of transformative technologies such as artificial intelligence (AI), Internet of Things (IoT), and big data analytics into transportation systems (Lin et al., 2017; Memon et al., 2017). However, the accessibility of ITS technologies in developing countries remains an open question, requiring further investigation into the socio-economic barriers to their adoption and scalability.

The citation trends indicate the sustained influence of foundational studies on subsequent research directions. For instance, widely cited works on eco-routing, AI-driven traffic management, and autonomous vehicles have shaped the thematic focus of the field (Pomerantseva et al., 2019; Yu et al., 2017). These studies have not only provided technological frameworks but have also addressed critical issues such as energy efficiency and urban mobility, underscoring their enduring impact. Despite these advancements, the lack of standardized sustainability metrics to evaluate ITS solutions is a significant limitation. Future research should establish robust, universally accepted frameworks to assess key dimensions such as emissions reduction, energy efficiency, and equitable access to mobility solutions. Developing such metrics would provide stakeholders with actionable tools to measure the long-term environmental and socio-economic impacts of ITS technologies.

The predictive analysis, which forecasts a stabilization in publication growth with approximately 950 annual publications by 2026, suggests that the field is maturing, transitioning from exploratory research to the practical implementation and optimization of ITS solutions. This phase of maturity presents opportunities to focus on scalability, standardization, and long-term sustainability. The integration of ITS technologies into existing transportation infrastructures, particularly in resource-constrained regions, will require targeted investments and tailored solutions that address local needs.

Geographic analysis reveals the global nature of ITS research, with India, China, and the United States leading in publication output. India's prominence is tied to national initiatives like the "Smart Cities Mission," which emphasizes the integration of smart technologies into urban planning and transportation infrastructure (Khosrowpour, 2019). China and the United States, by contrast, dominate in technological innovation, particularly in autonomous vehicles, IoT applications, and AI-powered systems (Ali et al., 2022; Bosco et al., 2024). Meanwhile, emerging economies such as Turkey and South Korea are gaining traction. In Turkey, the growth is driven by investments in smart city projects and national funding programs like those supported by TÜBİTAK. South Korea's advancements are tied to its strong ICT infrastructure and government initiatives to promote innovation in urban mobility. These developments highlight the importance of national policies and strategic investments in driving ITS research. However, further research is needed to quantify the specific contributions of these countries in areas such as AI, IoT, and sustainable transportation solutions.

Despite these contributions, the limited representation of developing countries in global ITS research highlights a critical gap. Collaborative programs and funding mechanisms should prioritize underrepresented regions to address region-specific challenges. For example, localized ITS solutions for traffic congestion or rural mobility could have transformative impacts if supported by adequate resources and research partnerships.

The collaborative dynamics of ITS research, as revealed through co-authorship networks, highlight the interdisciplinary nature of the field. Institutions such as MIT, Tsinghua University, and Delft University of Technology emerge as major hubs fostering innovation and knowledge dissemination. These networks emphasize the importance of international partnerships in addressing shared mobility challenges, such as congestion and environmental sustainability. However, the disparities in research representation suggest the need for more inclusive collaboration models that integrate institutions from underrepresented regions, enabling the co-creation of solutions tailored to diverse socio-economic contexts.

The thematic analysis underscores the dominant role of IoT, smart cities, and machine learning in shaping ITS research. These technologies have facilitated significant advancements, from real-time traffic optimization to predictive maintenance and adaptive routing. The increasing emphasis on sustainability is evident in the prevalence of terms like "eco-routing" and "renewable energy," reflecting the alignment of ITS research with global environmental objectives, including the United Nations Sustainable Development Goals (Susanty et al., 2023; Gamboa-Rosales & Celaya-Padilla, 2020). However, the lack of standardized metrics to evaluate the environmental impact of ITS solutions remains a notable gap, necessitating future research to establish robust assessment frameworks.

Despite its progress, ITS research faces challenges that must be addressed to unlock its full potential. Ethical concerns surrounding autonomous vehicles, particularly in decision-making during critical scenarios, remain unresolved. Questions of accountability, safety, and the displacement of traditional transportation jobs need to be tackled through interdisciplinary dialogue and stakeholder engagement (Wang et al., 2022). A possible solution could involve the development of ethical guidelines and policy frameworks, co-created with industry, government, and public stakeholders. Additionally, the integration of ITS into legacy transportation infrastructures poses technical and political challenges, especially in resource-constrained settings (Tomaszewska & Florea, 2018). These barriers highlight the need for context-specific solutions that balance technological innovation with socio-economic realities.

Human-centric design is another area that requires greater emphasis. While ITS research predominantly focuses on technological advancements, limited attention is given to user adoption and behavioral aspects. Future studies must explore how individuals and communities interact with ITS solutions to enhance their effectiveness and acceptance. Understanding the social dimensions of ITS can ensure that

these technologies are not only functional but also equitable and inclusive (Das & Sharma, 2022). Bridging the gap between technological innovation and user-centric approaches will require interdisciplinary research that integrates engineering, behavioral science, and urban planning.

The predictions from machine learning models used in this study suggest that areas like AI-driven traffic management, autonomous vehicles, and eco-friendly transportation solutions will dominate future research. These projections emphasize the critical role of ITS in addressing ongoing challenges such as urban congestion and climate change. However, achieving these objectives will require coordinated efforts from academia, industry, and policymakers to ensure that ITS technologies are effectively deployed and scaled.

Declaration of Contribution of Researchers

The authors' contribution rates to the study are equal.

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Conflict of Interest Statement

There is no conflict of interest with any institution or person within the scope of the study.

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