Heliyon 11 (2025) e42331

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Nonlinear impact of information technologies on the development of the aviation industry in Vietnam

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ARTICLE INFO

Keywords:
Air transport
Aviation industry
Freight traffic
IT engineering
Passenger traffic

ABSTRACT

The aviation industry plays a crucial role in the sustainable development of ASEAN countries; however, its progress is often hindered by the phenomenon of digital inequality. In the context of the internationalization and digitalization of the aviation industry—accompanied by the implementation of projects related to standardization procedures and environmental monitoring—research tasks aimed at examining the impact of IT engineering on key performance indicators of the aviation sector are of particular relevance. The aim of this study was to describe the relationship between the level of digitalization, particularly the development of IT engineering, and the main performance indicators of the aviation industry's growth, using Vietnam as a case study. The research objectives were focused on assessing the impact of digital technology adoption on the growth of passenger and cargo transportation, as well as identifying barriers that hinder the digitalization of the sector. The methodological design of the study was based on the application of correlation analysis and olynomial modeling. Statistical data on passenger traffic, cargo volumes, and IT engineering activity in Vietnam's aviation industry from 2012 to 2020 were utilized. The results confirmed a statistically significant relationship between the development of IT engineering and key indicators such as the number of passengers transported and the volumes of passenger and cargo traffic. The study also identified barriers, such as regulatory constraints in investment policy and a shortage of qualified personnel, which may impede the effective integration of IT engineering and digitalization projects in Vietnam's aviation industry. These barriers highlight the need for additional measures to ensure government support. The practical significance of the study lies in the potential application of the findings for developing national digitalization strategies for the aviation industry. The results may be of interest to the academic community and professionals involved in the development of the aviation sector.

1. Introduction

Currently, the aviation industry is undergoing significant transformations driven by the processes of digitalization in production, the implementation of new standards from the International Air Transport Association (ATA) [1], and international integration. For example, the "CATA ASEAN-EU » [2], agreement represents the world's first interbloc air transport agreement, involving 37 member

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https://doi.org/10.1016/j.heliyon.2025.e42331
Received 26 July 2024; Received in revised form 14 January 2025; Accepted 28 January 2025
Available online 28 January 2025

states from ASEAN and the EU. These standards have been developed and implemented to foster collaboration among industry participants, facilitate the effective integration of digital technologies into predictive maintenance processes [3], optimize supply chain management and aircraft operations, and create conditions for transitioning to sustainable aviation.

Overall, the aviation industry identifies several priority areas for digital transformation. Table 1 presents the key directions for the digital transformation of the aviation sector.

The key areas of investment activity in the aviation industry are projected to include "Cybersecurity" and "Cloud Services." In the coming years, 97 % and 95 % of airlines, respectively, are expected to undertake large-scale research and development (R&D) projects in three primary domains: aircraft maintenance, business analytics solutions, and digital tags [4]. Furthermore, in response to regulatory frameworks addressing emissions and industry benchmarks for carbon emission reduction [5], a surge in activities related to "greening through information technology" is anticipated. This approach involves leveraging information technologies and solutions to assist airlines in achieving sustainable development goals across all areas of operation, including environmental, social, economic, and managerial dimensions [6]. However, the process of digitalizing the aviation industry is uneven and accompanied by several challenges associated with digital inequality among countries and companies. Unequal access to advanced technologies creates conditions in which developing regions lack the resources necessary for technological renewal. Emerging markets often face shortages of reliable digital infrastructure required for the implementation of communication, surveillance, and navigation systems. One of the most significant issues is the digital literacy of employees, who must possess the competencies needed to operate modern digital systems.

Another critical challenge is environmental inequality. Airlines in developing countries, lacking access to artificial intelligence-based fuel management systems, sustainable aviation fuel (SAF), electric propulsion systems, and other innovations, contribute disproportionately to emissions despite having fewer flights. Consequently, airports with underdeveloped digital infrastructure, such as "smart airports" equipped with Internet of Things (IoT) and artificial intelligence technologies [7,8], face limitations in enhancing their competitiveness, exacerbating economic and social marginalization. Moreover, the uneven digitalization of aviation infrastructure hinders its development, particularly during crises such as the COVID-19 pandemic, further highlighting the need for equitable technological advancement across the sector [4,5]. The example of cargo air transportation in Vietnam demonstrated that the implementation of IT engineering not only mitigated the impact of the pandemic but also facilitated entry into new markets. Thus, the digitalization of aviation holds strategic significance for the globalization and economic development of developing countries. It creates opportunities for integration into international logistics chains, increases passenger and cargo transportation volumes, and provides additional avenues for attracting investment and strengthening international cooperation.

The scientific contribution of this study lies in its novel demonstration, based on data from Vietnam's developing economy, of a statistically significant relationship between key performance indicators of the aviation industry and its level of digitalization.

This approach opens new avenues for examining the impact of digital technologies on aviation in countries with transitional economies. The practical significance of the study lies in the development of recommendations for public policy and business, aimed at advancing the digitalization of the aviation industry. The findings can be utilized to design national strategies focused on accelerating the adoption of IT solutions, workforce training, and attracting investments in high-tech sectors.

The study has global relevance, as the conclusions can be extrapolated and applied to address challenges in the aviation services

Table 1
Key directions of digital transformation in the aviation industry.

Technology Name	Application Area	Innovation Advantage	Implemented projects
Big Data and Data Analytics	Processing large volumes of data on passengers, routes, and aircraft conditions to optimize flights, improve customer service, and reduce operational costs.	Improved management efficiency and reduced fuel costs.	Skywise by Airbus
Artificial Intelligence (AI)	Automating decision-making processes, demand forecasting, baggage management, and creating a personalized passenger experience.	Faster data processing and enhanced customer experience.	SITA AI Solutions for Airports
Internet of Things (IoT)	Using sensors on aircraft and at airports to monitor equipment conditions, track luggage, and manage logistics.	Enhanced flight safety and improved service quality.	GE Aviation IoT Platform
Digital Twins	Developing virtual models of aircraft, airports, and logistics systems to test operational and maintenance scenarios.	Reduced testing costs and improved predictive maintenance.	Digital Twin by Rolls-Royce
Automation and Robotics	Employing robots for aircraft maintenance, airport cleaning, and service operations.	Lower labor costs and increased accuracy and speed of task execution.	Robotic Systems by Airbus
Predictive Maintenance Systems	Collecting data on aircraft conditions through sensors and predictive algorithms to prevent malfunctions.	Enhanced safety and fewer unexpected flight delays.	Boeing AnalytX
Blockchain	Ensuring transparency and security of data related to passengers, cargo, and maintenance.	Reduced fraud risks and increased customer trust.	Lufthansa Innovation Hub
Cloud Technologies	Storing and processing airline and airport data on cloud platforms.	Lower IT infrastructure costs and improved data accessibility.	AWS for Airports
Customer Service Automation	Implementing chatbots, automated check-in kiosks, and self-service systems.	Shorter wait times and enhanced user experience.	AirAsia Chatbots
Virtual and Augmented Reality (VR/AR)	Utilizing VR/AR for pilot and ground staff training, as well as enhancing passenger experience.	Reduced training costs and improved employee readiness.	CAE VR Solutions
Cybersecurity	Ensuring data protection for passengers, flight management systems, and technical equipment from cyberattacks.	Lower risks and increased system resilience.	Lufthansa Allegris

market of other developing countries. This potential makes the results significant both for the academic community and for professionals engaged in the development of the aviation industry and the digital economy.

1.1. Literature review

The analysis of recent literature sources has shown that modern science has paid considerable attention to the issues facing the IT engineering and aviation industries as a result of the importance of these sectors for achieving sustainable development in developing economies [9–13]. However, it should be noted that the rapid advancement of IT engineering has resulted in a lack of progress in general theoretical areas, most notably the conceptual framework of this definition. For this reason, this study focuses on the recommendations issued by the International Council on Systems Engineering (INCOSE) [14]. These recommendations advocate for using the term "engineering" in its broadest sense, with engineering defined as "the action of skilled workers to achieve something" [14]. Using these recommendations as a guide, this study defines IT engineering as using IT technology to promote sustainable development. The analysis of theoretical sources showed that most present-day researchers concentrate on the specific uses of IT engineering in the aviation industry. The impact of Industry 4.0 software drivers on aviation maintenance is examined in a study by Ceruti et al. [15], including a list of the Industry 4.0 techniques most effective for maintaining aircraft. The predecessors focused on augmented reality and additive manufacturing technologies that could help with maintenance and spare parts production. The researchers found that augmented reality and additive manufacturing are useful tools in aviation maintenance. However, the widespread adoption of these technologies in aerospace systems maintenance requires the creation of a suitable regulatory framework [15].

Ibrion et al. [16] use the aviation industry as a case study to present the findings of a study on the potential dangers of implementing digital twins. The authors thoroughly examined the lessons learned from the Boeing 737 MAX crashes in Indonesia in 2018 and Ethiopia in 2019. They discovered that sensor reliability, model failure, and incorrect decisions due to data processing are among the risks associated with implementing digital twins. Using the example of accidents, it was discovered that the digital twin might not be able to represent all the possible scenarios the system may encounter throughout its lifetime. Although the digital twin has many benefits, its implementation is risky and uncertain, even in fields like aviation, where it is at a higher level of development and use than in the maritime sector.

Elhmoud and Kutty [17] examine the viability of the aviation industry in light of multiple environmental challenges. The researchers claim that the aviation industry has not done enough to support the UN Sustainable Development Goals, despite sporadic adoption of sustainable aviation practices. The researchers also believe that a major obstacle to the aviation industry's sustainable development is the growing volume of air traffic and its associated benefits. An overview of the tools and techniques used to evaluate the socioeconomic and environmental sustainability of the aviation industry is provided by earlier studies. It should be noted that the study also provides an overview of cutting-edge high-tech model methods, tools, and techniques for assessing sustainability, such as decision support systems (DSS) based on artificial intelligence (AI), deep learning, and neural network (NN) models [17].

Pham [18] examines the growth of a competitive air transport market in Vietnam in terms of significant difficulties and lessons learned for developing countries. With a focus on identifying the variables that directly affect air transport competition, the author thoroughly analyses the conditions of resource access in the Vietnamese air transport market. The paper also contains policy reform recommendations based on this analysis to promote a competitive market that may be relevant to the growth of the air transport market in Vietnam and other emerging and transitional economies.

Consequently, the findings of the analysis of current scientific publications on the subject of the research have demonstrated that, despite the significant interest of researchers in the issues of sustainable development of the aviation industry and active search for optimal influencing factors, the issue of the relationship between IT engineering and development of the aviation industry at the time of research is underdeveloped. A significant portion of the research is applied in nature and addresses a specific, focused issue in the aviation industry [19–21]; a second, equally significant portion of the research primarily analyses and evaluates the impact of the COVID-19 pandemic on the development of the aviation industry [22–24]. Meanwhile, much of the research is review-oriented [25–27]. Nonetheless, there is a clear dearth of research examining the interrelationships and mutual influences of IT engineering and the growth of the aviation industry.

1.2. Problem statement

In the context of global transformation, the development of the aviation industry has encountered challenges related to the implementation of digital technologies. The digital divide has significantly impacted developing countries, limiting their access to innovative solutions and slowing the growth of aviation infrastructure. On the other hand, the integration processes within the global aviation services market necessitate adaptation to new IATA standards, which emphasize the digitalization of supply chain management, predictive maintenance, and aircraft operations. However, the uneven distribution of digital resources, low digital literacy among personnel, and the lack of digital infrastructure hinder the adoption of IT solutions and innovations in developing markets.

The process of digitalizing the aviation industry requires not only substantial investments but also appropriate policy decisions at the level of state governance. In the context of resource scarcity—not only in financial but also intellectual resources [28], governments of developing countries, investment companies, and active players in the aviation services market must have a clear understanding of priorities when making decisions to create conditions conducive to the successful implementation of IT-engineering projects.

Within this framework, the aim of the study was to describe the relationship between the level of digitalization and key performance indicators of the aviation industry in developing countries. Specifically, the study sought to determine the statistical significance of the influence of digitalization, particularly IT engineering, on key indicators of aviation industry development, such as passenger and cargo air transport volumes, using developing countries as a case study.

Achieving this aim involves testing the following hypotheses:

Hypothesis 1. (H1): Number of air passengers carried directly correlates with the development of IT engineering. The issue of low digitalization significantly limits passenger transportation in developing countries. The successful implementation of IT engineering can contribute to increasing passenger volumes by optimizing routes, enhancing the user experience, and reducing costs.

Hypothesis 2. (H2): Volume of air passenger traffic directly correlates with the development of IT engineering. Digitalization impacts the development of services such as online check-in, automated baggage handling, and predictive maintenance systems, enhancing capacity and passenger satisfaction while driving growth in transportation volumes.

Hypothesis 3. (H3): Volume of air freight directly correlates with the development of IT engineering.

Hypothesis 4. (H4): Volume of air freight traffic directly correlates with the development of IT engineering. Amid the growing demand for cargo transportation, particularly in the post-pandemic period, the implementation of IT engineering enables effective management of logistics chains, enhancing reliability and increasing cargo volumes.

In line with the research aim and the formulated hypotheses, the main objectives of the study are as follows:

– To analyze the current level of digitalization in Vietnam's aviation industry, with a focus on the development of IT engineering;
– To examine the relationship between the level of digitalization and the volumes of passenger and cargo air transportation using statistical analysis methods;
– To evaluate the impact of IT engineering on key performance indicators of Vietnam's aviation industry, such as the number of passengers transported and cargo volumes;
– To identify specific barriers hindering the adoption of digital technologies in the aviation sector;
– To determine priority areas for the development of public policy aimed at accelerating the digitalization process and enhancing the competitiveness of the aviation industry.

2. Methods and materials

The methodological design of this study was focused on examining the relationship between the development of IT engineering and the key performance indicators of Vietnam's aviation industry during the period from 2012 to 2020.

Vietnam was chosen as the testing location. The following arguments were used to select a country for testing:

1. Rapid growth: Vietnam's aviation industry is one of the three fastest-growing in Southeast Asia [29] and is recovering from the COVID-19 pandemic at the fastest rate [30].
2. Vietnam's strategic location in Southeast Asia and proximity to the largest regional economies enables it to benefit from its territorial logistics centre, including for connecting flights [31].
3. Government support, including both a favourable legal and regulatory framework and substantial public investment in developing the aviation industry, modernising infrastructure, enhancing flight safety, and expanding international cooperation.
4. Strong partnerships with leading international airlines and organisations to pursue further growth in the industry.

To achieve the research objectives, a comprehensive approach was employed, incorporating statistical modeling and correlation analysis. Data collection was conducted in four stages: identification of key indicators, selection of relevant information sources, data standardization, and subsequent processing. The primary focus was on obtaining statistical data reflecting the dynamics of Vietnam's aviation industry and sectoral indicators related to the implementation of IT engineering projects during the period from 2012 to 2020.

In the initial stage of the study, key indicators necessary for hypothesis testing were identified. To describe the dynamics of the aviation industry's development, the following metrics were used: "number of passengers transported," "passenger traffic volume," "cargo transportation volume," and "cargo turnover." To assess the level of activity in implementing IT engineering projects, data on "the number of patent applications filed by residents and non-residents" and "high-tech exports" (both in monetary terms and as a percentage of industrial exports) were utilized.

The primary sources of information on the dynamics of the aviation industry included official government reports, such as statistical bulletins from the General Statistics Office of Vietnam [32], as well as analytical reports from national aviation agencies and platforms providing industry data and analytics.

To ensure the reliability of the research results, a standardized data processing procedure consisting of several stages was applied. In the first stage, a thorough analysis of the data was conducted to identify missing values and anomalies. Missing values were addressed using the linear interpolation method, which preserved the data structure and prevented distortions. The interquartile range (IQR) method was used to detect outliers, with values exceeding 1.5 IQR classified as outliers and excluded from further analysis. This approach minimized the impact of extreme values on the study results.

Subsequently, data normalization was performed to unify the scales of various variables and ensure the correct application of statistical methods. The final stage involved verifying the reliability of the processed data. The dataset was supplemented and cross-checked against information from international industry reports, including materials from the International Air Transport Association

(IATA) and the International Civil Aviation Organization (ICAO).

The assessment of IT engineering project development and implementation activity was based on data from open reports by the World Bank Group [33] and the World Intellectual Property Organization (WIPO). Particular attention was paid to analyzing the dynamics of indicators in the context of significant events, such as the COVID-19 pandemic, which had a substantial impact on the aviation industry.

The collected data were systematically organized into a unified database that captured the dynamics of each indicator over the study period. This database served as the foundation for constructing regression models and conducting correlation analysis. The measures undertaken ensured high data quality, which was critical for subsequent statistical analyses and the development of well-substantiated conclusions. Thus, the structured approach to data collection provided representative and reliable information necessary to achieve the study's objectives.

The analysis of the collected data was conducted using correlation analysis, polynomial regression, and statistical time series analysis.

To test the first hypothesis (H1), correlation analysis was employed, with coefficients calculated to measure the relationship between the number of passengers transported and IT engineering indicators (such as the number of patent applications filed by residents and the volume of high-tech exports). The correlation coefficients were computed using the following formula:

$$Correl(X,Y) = \frac{\sum (x-\underline{x})\left(y-\underline{y}\right)}{\sum (x-\underline{x})^2 \sum \left(y-\underline{y}\right)^2} \tag{1}$$

where $\underline{x,y}$ are the mean values of the samples.

To test the second (H2) and third (H3) hypotheses, polynomial regression was applied. Fifth-degree polynomial models were used to describe the dynamics of passenger traffic over the entire study period from 2012 to 2020. The choice of a fifth-degree polynomial regression was based on the assumption that the relationship between aviation indicators (passenger traffic, cargo turnover) and the development of IT engineering is nonlinear. Furthermore, a fifth-degree polynomial offers sufficient flexibility to approximate complex curves.

Preliminary data analysis, including scatterplot visualization to evaluate the nature of relationships between variables during the data preparation stage, indicated that a fifth-degree model adequately captures the relationships studied in this research. On the other hand, higher-degree polynomials may lead to overfitting and reduced interpretability, while lower-degree polynomials might fail to capture the full complexity of the relationships.

Thus, employing fifth-degree polynomial regression allows not only the identification of the existence of a relationship between the aviation industry and the development of IT engineering but also a detailed characterization of this relationship, which is particularly significant in the context of the hypotheses. This method enables the modeling of nonlinear relationships, which are hypothesized to exist between the studied variables, and enhances the objectivity of the findings. The formula for the polynomial regression was as follows:

$$y = ax^5+bx^4+cx^3+dx^2+ex + f \tag{2}$$

where y represents passenger traffic volume, denotes the year, and the coefficients a,b,c,d, and e, were determined using the least squares method.

This model enabled the identification of key patterns and changes in the dynamics of the aviation industry. For each model, coefficients of determination R^2, were calculated through a multi-step process. In the first stage, a fifth-degree polynomial model was applied to each dataset, such as passenger traffic or cargo turnover. This model generated predicted values for each year using the calculated model coefficients. Subsequently, the sum of squared residuals (SSR) was calculated. This involved subtracting each predicted value from the corresponding actual data value, squaring the resulting deviations, and summing these squares to obtain the SSR, which reflects the model's prediction error.

Simultaneously, the total sum of squares (SST) was calculated to capture the overall variability in the dataset. SST represents the differences between each actual value and the dataset's mean. To compute SST, deviations from the mean were squared and summed. Finally, the coefficient of determination was calculated using the following formula:

$$r^2 = 1 - \frac{SSR}{SST} \tag{3}$$

This study is subject to several methodological limitations.

First, the use of time series models with fifth-degree polynomial functions entails certain assumptions regarding the structural stability and continuity of the data. However, the dynamics of Vietnam's aviation industry, particularly under external shocks such as the COVID-19 pandemic, may undergo significant and abrupt changes that the model cannot always accurately account for. These assumptions reduce the precision of forecasts during periods of socio-economic and political instability, as time series data may exhibit sharp deviations. Second, the study relies on data covering the period from 2012 to 2020. The duration of this time horizon may not capture longer-term trends or earlier developmental stages of the aviation industry, thus limiting researchers' ability to draw conclusions about the characteristics of long-term trends. Additionally, the scope of the study is geographically confined to the Vietnamese market, making a full extrapolation of the findings to other countries' experiences unlikely to be entirely valid. One key limitation is the lack of sensitivity analysis for the fifth-degree polynomial regression model, which could further enhance the robustness of the findings. Undoubtedly, the use of high-degree polynomial regression models introduces the potential for sensitivity of results to changes in the input data and model parameters. While measures were taken to ensure the quality of the input data—such as checking for missing values and outliers, data normalization, and verification using reports from IATA and ICAO—the absence of a comprehensive sensitivity analysis prevents us from fully eliminating the influence of this factor.

This limitation is primarily due to the resources available for this study, which necessitated a focus on addressing the core research objectives. Consequently, the findings of this study should be interpreted with this limitation in mind. Sensitivity analysis is identified as a priority area for future research.

The Microsoft Excel spreadsheet processor's software features, including the ability to visualise the results, were used in this study.

3. Results

The analysis of the aviation industry dynamics in Vietnam from 2012 to 2020 is shown in Table 2.

The analysis of key Vietnamese aviation indicators for the period 2012–2020 reveals that the aviation industry in Vietnam has experienced rapid expansion for nearly the entirety of the period under review. Meanwhile, more research needs to be done on the dynamics of each indicator of passenger traffic.

Fig. 1 illustrates the dynamics of the number of air passengers transported by Vietnamese airlines from 2012 to 2020.

As shown in Fig. 1, the number of air passengers steadily increased from 15,069.5 thousand in 2012 to a peak of 55,079.56 thousand in 2019. The primary drivers of this growth included the expansion of routes, modernization of infrastructure, and the implementation of IT engineering solutions, which significantly enhanced the efficiency and convenience of air transportation.

The quarantine measures connected to the COVID-19 pandemic were blamed for the dramatic decrease in the number of passengers carried by air in 2020. A degree-5 polynomial model describes the presented dynamics: $y = -42.234 \times ^5 + 974.18 \times ^4 - 8449.7 \times ^3 + 33870 \times ^2 - 54702x + 43{,}584$. The approximation reliability value $R^2 = 0.9936$ indicates a very high model fit and the feasibility of forecasting using the constructed model.

The increase in the number of passengers transported up to 2019 highlights the positive impact of IT engineering on the development of the aviation industry, supporting Hypothesis H1: the number of passengers transported is directly correlated with the implementation of digital technologies.

Fig. 2 presents the dynamics of passenger air transportation volume in Vietnam from 2012 to 2020, measured in millions of passenger-kilometers.

The data presented in Fig. 2 demonstrate that from 2012 to 2019, passenger air transportation volumes steadily increased, rising from 23,626 million passenger-kilometers in 2012 to 77,402.83 million in 2019. The significant growth in passenger traffic volume during 2018–2019 can be attributed to advancements in IT engineering, which enabled improved route optimization, process automation, and enhanced passenger service quality. However, in 2020, the transportation volume sharply declined to 34,124.88 million passenger-kilometers due to restrictions on international and domestic flights imposed in response to the COVID-19 pandemic. These restrictions significantly reduced demand for air travel and limited passenger mobility.

A degree-5 polynomial model describes the presented dynamics: $y = -86.85 \times ^5 + 1945.8 \times ^4 - 16047 \times ^3 + 59942 \times ^2 - 92318x + 70{,}495$. The approximation reliability value $R^2 = 0.9954$ indicates a very high model fit and the feasibility of forecasting using the constructed model. The developed models of the number of air passengers carried and air passenger traffic (degree-5 polynomial) dynamics have a significant type similarity due to both the interrelationship of the analysed values and quarantine restrictions due to the COVID-19 pandemic as the common impact factor.

Thus, it can be concluded that the growth in transportation volumes up to 2019 supports Hypothesis H2: passenger air transportation volume is directly correlated with the implementation of digital technologies. IT solutions such as online check-in, automated baggage handling, and predictive maintenance have had a significant positive impact on this indicator.

Fig. 3 presents the dynamics of cargo turnover in air transportation in Vietnam from 2012 to 2020, measured in million ton-kilometers.

The data indicate that from 2012 to 2019, the cargo turnover of Vietnamese airlines steadily increased, rising from 475.1 million ton-kilometers in 2012 to a peak of 922.5 million ton-kilometers in 2019. The acceleration in growth during the later years can be attributed to increasing demand for international cargo transportation and the adoption of IT engineering solutions, which optimized routing and improved cargo flow management.

In contrast to other indicators, cargo turnover rose sharply in 2020, reaching 3562.05 million ton-kilometers. This significant growth was driven by the expansion of Vietnamese carriers' operations in international markets, facilitated by the rapid implementation of digital technologies. Additionally, this increase was necessitated by the need to offset the decline in passenger transportation during the COVID-19 pandemic.

A degree-5 polynomial model describes the presented dynamics: $y = 3.1804 \times ^5 - 68.723 \times ^4 + 543.26 \times ^3 - 1912.2 \times ^2 + 2948.7x - 1056.6$. The approximation reliability value $R^2 = 0.9923$ indicates a very high model fit and the feasibility of forecasting using the constructed model. The developed models of the air freight and air freight traffic (degree-5 polynomial) dynamics have a significant type similarity due to both the interrelationship of the analysed values and quarantine restrictions due to the COVID-19 pandemic as the common impact factor.

Thus, the data analysis confirms Hypothesis H4: IT engineering drives the growth of key performance indicators in the aviation industry, including cargo turnover, by enhancing the efficiency and reliability of logistics.

The correlation analysis method is used to investigate the relationships and mutual influences of the dynamics of the aviation industry and IT engineering development in Vietnam. Table 3 shows the results of the two-factor correlation between the key

Table 2
Key Vietnamese aviation indicators, 2012–2020.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	μ	σ
Number of air passengers carried (thousand people)	15069.50	16891.00	24431.40	31150.00	38591.00	44556.00	49076.80	55079.56	32336.68	34131.33	13953.22
Volume of air passenger traffic (million people km)	23626.00	26877.70	34707.50	42068.40	48236.60	54314.40	67856.00	77402.83	34124.88	45468.26	18322.34
Volume of air freight (thousand tonnes)	191.00	183.70	202.00	229.60	285.60	317.90	404.40	446.42	272.38	281.44	93.87
Volume of air freight traffic (million tonnes km)	475.10	469.80	534.40	599.50	705.00	748.80	837.16	922.50	3562.05	983.81	979.68

Source: Calculated by the authors

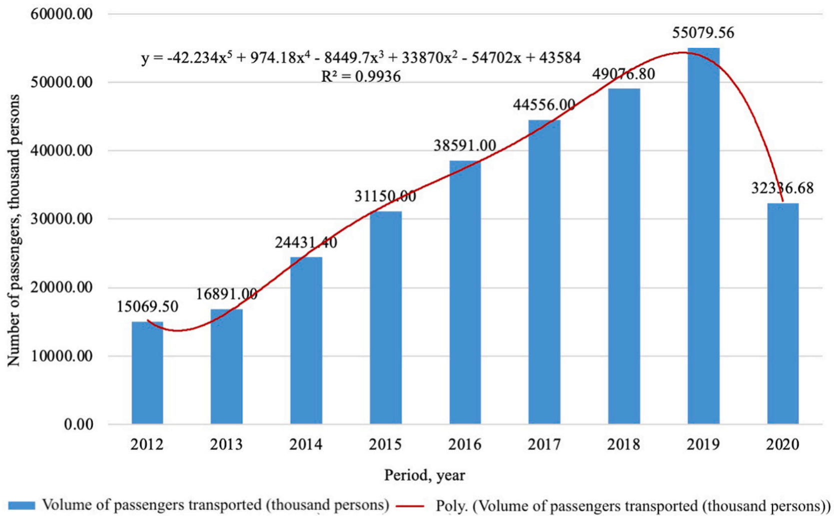

Fig. 1. Number of passengers transported by Vietnamese airlines, 2012–2020 (thousands).
Source: Developed by the authors

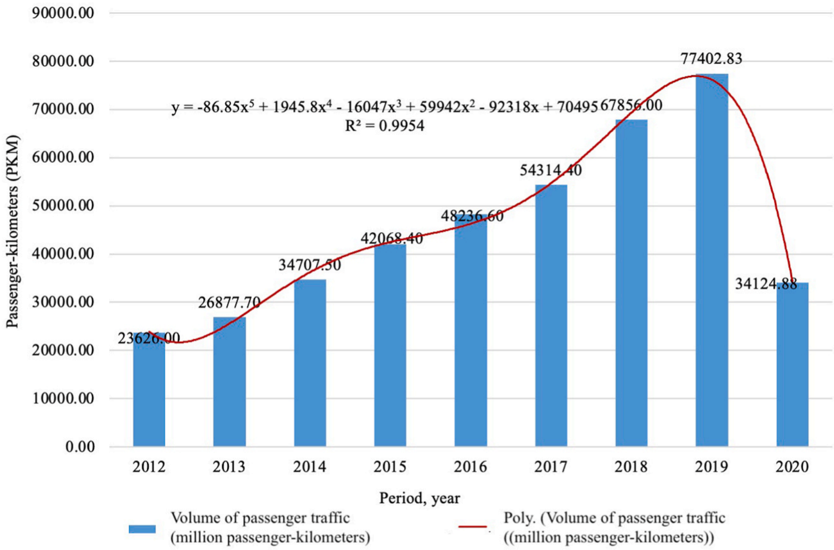

Fig. 2. Passenger Traffic Volume of Vietnamese Airlines (RPK), 2012–2020 (million passenger-kilometers).
Source: Calculated by the authors

indicators of Vietnam's aviation industry and IT engineering.

Next, a correlation analysis will be conducted to examine the relationship between key performance indicators of Vietnam's aviation industry and IT engineering development metrics for the period from 2012 to 2020. Indicators such as the number of patent applications filed by residents and non-residents, the volume of high-tech exports (in current prices and as a percentage of industrial exports), and their impact on aviation performance metrics will be analysed. The results of the analysis will confirm the relationship between key development indicators of Vietnam's aviation industry and the primary digitalization metrics associated with IT engineering.

Table 3 presents the results of the correlation analysis between the key performance indicators of Vietnam's aviation industry and the metrics of IT engineering development for the period from 2012 to 2020.

By number of air passengers carried, the analysis results show that the correlation with IT engineering indicators ranges from high (Correl>0.4) for patent applications filed by residents (0.49) to very high (Correl>0.75) for patent applications filed by residents (0.76), high technology exports (in current US dollar prices) (0.80), and high technology exports (% of industrial exports) (0.83), suggesting a very strong relationship between the indicators. Thus, the analysis results support hypothesis (H1): Number of air passengers carried directly correlates with the development of IT engineering.

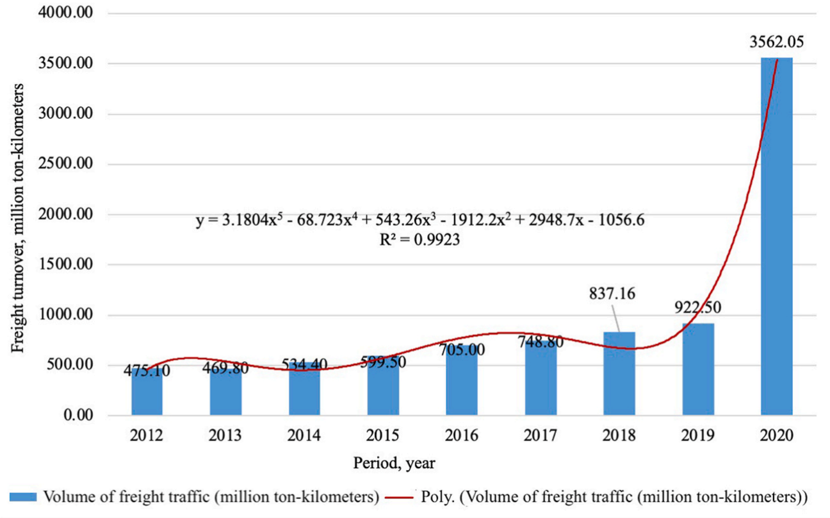

Fig. 3. Cargo Turnover of Vietnamese Airlines, 2012–2020 (million ton-kilometers).
Source: Calculated by the authors

Table 3
The two-factor correlation between the key indicators of Vietnam's aviation industry and IT engineering.

	Patent applications filed by non-residents	Patent applications filed by residents	High technology exports (in current US dollar prices)	High technology exports (% of industrial exports)
Number of air passengers carried (thousand people)	0.76	0.49	0.80	0.83
Volume of air passenger traffic (million people km)	0.66	0.32	0.67	0.7
Volume of air freight (thousand tonnes)	0.78	0.47	0.79	0.74
Volume of air freight traffic (million tonnes km)	0.67	0.91	0.68	0.49

Source: Calculated by the authors

By air passenger traffic, the correlation with IT engineering indicators varies from sufficient (Correl>0.2) for patent applications filed by residents (0.32) to high (Correl>0.4) for patent applications filed by residents (0.66), high technology exports (in current US dollar prices) (0.67), and high technology exports (% of industrial exports) (0.70), suggesting a sufficient and strong relationship between the indicators. Thus, the analysis results support hypothesis (H2): Volume of air passenger traffic directly correlates with the development of IT engineering.

By air freight, the correlation with IT engineering indicators ranges from high (Correl>0.4) for patent applications filed by residents (0.47) and high technology exports (% of industrial exports) (0.74) to very high (Correl>0.75) for patent applications filed by non-residents (0.78) and high technology exports (in current US dollar prices) (0.79), suggesting a strong to very strong relationship between the indicators. Thus, the analysis results support hypothesis (H3): Volume of air freight directly correlates with the development of IT engineering.

By air freight traffic, the correlation with IT engineering indicators ranges from high (Correl>0.4) for patent applications filed by non-residents (0.67), high technology exports (in current US dollar prices) (0.68), and high technology exports (% of industrial exports) (0.49) to very high (Correl>0.75) for patent applications filed by residents (0.91), suggesting a strong to very strong correlation between the indicators analysed. The analysis results support hypothesis (H4): Volume of air freight traffic directly correlates with the development of IT engineering.

Overall, the results obtained from the analysis of key performance indicators in Vietnam's aviation industry and the development of IT engineering confirm the hypotheses proposed in the study. IT engineering projects and the process of digitalization have a significant impact on the key performance metrics of Vietnam's aviation industry. This relationship is particularly evident in the changes observed in high-tech export metrics, which show a strong correlation with passenger transportation, and in resident patent activity, which has a substantial influence on cargo turnover.

The findings confirm that IT engineering is one of the critical factors driving the development of the aviation industry amidst the digital transformation of Vietnam's aviation sector.

However, despite the fact that this study has demonstrated the interdependence between the development of IT engineering and the positive growth dynamics of key industry indicators, several significant barriers may negatively impact the digitalization process of

Vietnam's aviation industry.

First, there are regulatory constraints that increase risks for foreign investors. For instance, Decree 89/2019/ND-CP [34], establishes a limitation that foreign capital ownership in the aviation sector must not exceed 34 % of an airline's charter capital. This restriction does not align with business expectations, particularly when compared to other ASEAN countries. Unlike Vietnam, Singapore, Brunei, Cambodia, Myanmar, and Laos impose no specific limitations on capital ownership. Thailand, Malaysia, and Indonesia permit foreign ownership of up to 49 % in the aviation sector, while in the Philippines, the limit is set at 40 % [35]. This disparity places Vietnam at a disadvantage in attracting foreign investors who seek greater control and influence over their investments. Another significant challenge in Vietnam's B2G market is the lack of transparency in tender information and evaluation processes, which limits the entry of new participants into the aviation services market [36].

Moreover, the Vietnamese market is characterized by a high level of competition and rapid growth. Notably, the low-cost carrier segment is expanding rapidly, dominated by VietJet Air, which accounted for 37.6 % of all domestic flights in Vietnam during the first half of 2023 [37]. As a result, foreign investors currently perceive direct investments in the aviation sector as high-risk. Industry experts instead recommend focusing investment activities on related sectors, such as in-flight catering, spare parts manufacturing, and training services.

Another factor that could negatively impact the digitalization processes in Vietnam's aviation industry is workforce challenges, which affect not only the aviation services market but also the development of IT engineering projects. According to IATA, between 2015 and 2035, Vietnam is among the top four markets with the highest growth rates in air passenger volumes. This growth will inevitably drive the development of industry infrastructure and create additional employment opportunities.

However, Vietnam's human resources in the aviation industry currently meet only 40 % of the demand. Experts predict that Vietnam's aviation sector will face a shortage of personnel in key areas such as airport management, ground handling, aircraft manufacturing, aircraft maintenance, and pilots [38]. This shortage is not merely a matter of quantity but also of quality and experience.

The second challenge pertains to staffing for aviation IT engineering projects. Vietnam's IT services market is characterized by a large number of young individuals, with an average age of just 30 years, representing a substantial pool of technically skilled workers capable of quickly adapting to new technologies. Additionally, Vietnam boasts a strong educational system that produces a significant number of graduates in science, technology, engineering, and mathematics (STEM). The government has also made substantial investments in infrastructure and technology, implementing initiatives such as the National Innovation Center and the Digital Transformation Program. Furthermore, the cost of labor in Vietnam is relatively low compared to other countries in the region, making it an attractive destination for IT service outsourcing [39]. However, these advantages suggest that a lack of investment and budget constraints in the aviation industry could render it unattractive to Vietnamese IT specialists. This would significantly reduce the intellectual capital available to the industry and increase reliance on costly foreign solutions in aviation IT engineering. While it is possible that the traditions of national business culture may mitigate the impact of macroeconomic factors [40], the fact that managing the aviation sector is a strategic priority for the state diminishes the likelihood of a positive shift in addressing the industry's workforce shortages.

In summary, it should be noted that the successful synergy between IT engineering projects and the digitalization trajectories of Vietnam's aviation industry is currently at risk due to the influence of not only intra-industry challenges but also external market conditions. These include workforce shortages, budget constraints, and a lack of government support.

The aforementioned issues necessitate further scientific research into the conditions required for the successful integration of digital technologies into Vietnam's aviation infrastructure, as well as increased attention and support from the Vietnamese government.

4. Discussion

Due to the significance of the aviation industry to the sustainable development of regional, national, and global economies, there has been a great deal of academic interest in the aviation industry development and the key factors influencing it [15,41,42]. Thus, Arena and Aprea [43] examined the effects of the COVID-19 pandemic on air transport. The authors provided an analysis of the dynamics of key indicators affected by the COVID-19 pandemic and the quarantine restrictions put in place by most governments to safeguard their citizens from the deadly virus, as well as an analysis of the environmental effects of this impact. Even though the earlier study by Arena and Aprea [43] is significant and timely, it is a review study that only considers the COVID-19 pandemic's effects and quarantine regulations, leaving the impact of IT engineering outside their scope.

Another aspect of greening the aviation industry is the transition to sustainable aviation fuel (SAF), which is used to decarbonize medium- and long-haul flights. Aircraft operating on these routes are responsible for the highest emissions. However, as previously mentioned, IATA considers addressing issues related to the adoption of SAF a key element in reducing the environmental impact of aviation [44,45]. Overall, environmental protection remains one of the most pressing challenges facing the global community and necessitates the search for innovative solutions to create conditions for its effective management [46].

Laplace et al. [47] present the results of a large-scale study of the economic impact of the Association of South East Asian Nations' (ASEAN) Single Aviation Market on several developing economies, including Cambodia, Laos, Myanmar, the Philippines, and Vietnam. The previous studies estimate a model that expresses the relationship between economic development and the aviation industry in terms of passenger numbers for each country. This model is based on an econometric model that calculates the economic impact of air transport liberalisation in Cambodia, Lao People's Democratic Republic, Myanmar, the Philippines, and Vietnam before the implementation of Article 5 of the European Convention on Human Rights (Right to Liberty and Security). The developed econometric model is then used to forecast the potential impact of the air industry on GDP growth in the countries studied, based on air passenger growth scenarios from 2014 to 2020. The predecessor study is timely and valuable to both the industry's sustainable development and national economies of the countries analysed. However, the researchers' study focuses on establishing the interdependence of air transport market liberalisation within ASEAN, with no consideration given to how IT engineering may affect the aviation industry growth.

The study on cybersecurity in the aviation industry by Ukwandu et al. [48] is also noteworthy. The authors say that the increased integration of information and communication technology (ICT) tools into everyday mechanical devices in the aviation industry has raised real economy concerns about air travel security. Furthermore, the introduction of electronically controlled aircraft and smart airports has worsened problem. A group of advanced persistent threats (APTs) should be regarded as the primary threats to the aviation industry, according to a review of cyberattacks in the sector over the previous 20 years. ARPs work with a specific state actor to steal intellectual property and intelligence while monitoring, infiltrating, and disrupting the capabilities of other sovereign nations, with malicious hacking for unauthorised access being the most common attack [48]. The results of Ukwandu et al. [48] can be used to forecast future cyberattack trends. Furthermore, they will enable the implementation of preventative measures to safeguard vital aviation industry infrastructures. Although the importance of the predecessor study [48] cannot be denied, it should be noted that the researchers approached the problem primarily from the cybersecurity perspective. In contrast, the present study examines the impact of IT engineering on the aviation industry as a whole.

The determinants of blockchain adoption in the aviation industry were the focus of Li et al. [49]. The authors used the technology adoption model to explain why the aviation sector wants to adopt blockchain technology for future advancements. The hypotheses were analysed and tested using a two-stage structural equation modelling approach with confirmatory factor analysis [49]. Their findings show that traceability, digital governance, regulatory and industry standards, technological advancements, and efficiency optimization have a positive impact on blockchain adoption intentions. Although the results are unquestionably important, it should be noted that the predecessors' research concentrated on the blockchain. In contrast, the present study examines the connections and mutual influences of the airline industry from the perspective of IT engineering in general from a broader perspective.

Thus, despite a large number of scientific publications on the sustainable development of the aviation industry, the present study not only confirms the findings of earlier investigations but also provides evidence of long-term, direct relationships between the development of the aviation industry and IT engineering. Moreover, IT engineering drives the aviation industry and positively influences its key indicators. Thus, the paper's scientific contribution comes from the authors' confirmation of the connections between the development of the aviation industry and IT engineering and their discussion of promising research avenues for the future.

5. Conclusion

The results of the study confirmed the statistical significance of the relationship between the development of IT engineering and the key performance indicators of Vietnam's aviation industry. They also validated that digitalization is one of the key factors driving its development.

An analysis of IT engineering activity and changes in passenger numbers demonstrated that the implementation of digital technologies improves service quality and optimizes passenger service processes. The high correlation between these indicators confirms that digitalization accelerates flight routing processes, automates customer interactions, and enhances the user experience. The analysis of passenger traffic volumes revealed that technological innovations such as automated baggage handling, the introduction of predictive maintenance systems, and the development of online services directly contribute to increasing airport capacity. The findings show that IT infrastructure projects in the aviation sector have enabled Vietnam to effectively manage passenger traffic growth, even during global crises such as the COVID-19 pandemic.

Similarly, an analysis of cargo transportation dynamics showed that the integration of IT solutions into logistics management systems creates new opportunities for optimization. Advanced monitoring, forecasting, and control systems not only increase cargo volumes but also enhance their reliability. The relationship between the level of digitalization and cargo turnover highlighted the critical role of integrating technologies such as the Internet of Things (IoT) and big data analytics. These technologies typically ensure supply chain transparency, reduce costs, and accelerate cargo processing. The experience of Vietnamese companies that adopted these solutions demonstrates their ability to strengthen positions in international markets and improve competitiveness under crisis conditions.

Overall, the study demonstrated that digitalization, particularly IT engineering projects, has become a key factor influencing the sustainability of the aviation industry's development. The confirmation of all hypotheses enabled the identification of mechanisms through which digitalization shapes trends in the aviation sector. Additionally, the study highlighted obstacles such as restrictive legislation, workforce shortages, and deficiencies in government regulations regarding foreign investment, which significantly hinder the development of Vietnam's aviation industry. These identified issues allowed for the refinement of priority areas in public policy to ensure further progress in the sector's development.

Thus, the research not only affirmed the importance of IT engineering for Vietnam's aviation industry but also identified key areas requiring special attention from the Vietnamese government. The integration of digital technologies is already improving operational performance, reducing the environmental footprint, and enhancing flight safety. However, achieving maximum impact requires more decisive actions in areas such as government regulation, investment, and workforce development.

In summary, the findings can serve as a foundation for developing strategies to digitalize the aviation industry and enhance its competitiveness.

CRediT authorship contribution statement

Duc Sinh Hoang: Validation, Software, Methodology, Conceptualization. **Hanh Thi My Ly:** Resources, Investigation, Formal analysis. **Phat Pham Tien:** Writing – review & editing, Writing – original draft, Data curation. **Zuzana Tučková:** Visualization, Supervision, Project administration, Funding acquisition.

Data availability

Data will be available on request.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing 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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