Embracing the Future: Adoption of Industry 4.0 in the Aviation Industry

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Abstract

The invention of the cyber-physical and intelligent system has ushered the world into the fourth industrial revolution known as Industry 4.0, which has crept into almost every type of industry. The aviation industry, one of the heavy technology dependents, is most sensitive to technological changes. However, little literature is available on this field related to Industry 4.0. Thus, this study bridged the gap in the literature and explored the relevant Industry 4.0 technologies of the aviation industry. Initial data were collected from a systematic literature review of articles published till 2023. In contrast, primary data related to the aviation industry was gathered through a questionnaire from experts in the field and analyzed through the fuzzy Delphi method. The result of the systematic literature review revealed that 19 identified technologies of Industry 4.0. In contrast, only fifteen are relevant for the aviation industry, with an average fuzzy score of more than 0.5, with digitization as the most important. The findings of this research will be beneficial for academia as a foundation of theory building, further research, and practical utilization for managers in the aviation industry.

Keywords: Industry 4.0, Aviation Industry, Exploratory Research, Fuzzy Delphi

1 Introduction

The 4th Revolution in industries, called Industry 4.0, is transforming the manufacturing sector at an unprecedented pace. As we stand on the cusp of a new era, integrating advanced digital technologies into traditional working processes revolutionizes how an organization performs its function to achieve the desired goals. Industry 4.0 represents a paradigm shift, where automation, data exchange, Artificial Intelligence (AI), and the Internet of Things (IoT) converge to create a highly interconnected and intelligent manufacturing ecosystem and have a different impact on

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every sector and industry (Javaid et al., 2022). Industry 4.0 is an incremental improvement in manufacturing practices and a fundamental change in industries' operations. The advent of steam power in the late 18th century marked the beginning of the First Industrial Revolution, which mechanized production. The Second Industrial Revolution was characterized by the assembly line and mass production, followed by the introduction of electricity and new manufacturing processes. The Third Industrial Revolution brought about the digital age with the rise of computers and automation. Currently, (Culot et al., 2020) are observing the rise of cyber-physical systems that combine the physical and digital domains, known as Industry 4.0

Industry 4.0 is the future, and a tremendous amount of work is being done in this field, yet just the tip of an iceberg is revealed, and many areas are still to be discovered. This revolution has encroached in all industries, with different technologies for each type of organization having varying impacts. Therefore, having accurate information about the technologies of Industry 4 impacting that industry is pertinent. Until now, no study has been carried out to explore the technologies of Industry 4.0 affecting the aviation industry. This study investigates the technological advancements of Industry 4.0 that influence the aviation industry.

The significance of this study can be well imagined because it is one of the booming industries and holds a strategic position as the gateway between nations (Ukwandu et al., 2022). Furthermore, the aviation industry is heavily technology-dependent, and even a mild technological shift amplifies its effect. The result of this study will explore and provide knowledge about the technologies that impact the industry and guide towards better utilization and adaption of these technologies. The global industries are quickly being transformed by a new revolution called Industry 4.0. The revolution involves integrating advanced manufacturing processes with information technology to create intelligent systems. Many firms worldwide strive to adopt Industry 4.0, a new trend focusing on automation and data interchange (Caiado et al., 2021). The phrase "Industry 4.0" was initially introduced in 2011 in Germany by a working committee commissioned by the RUE-Science of the German Ministry of Education and Research. The team presented the concept at the Hanover Fair (Culot et al., 2020). This offers a novel perspective for expanding business and fostering future innovation (Javaid et al., 2022). The successful execution of strategic initiatives to incorporate Industry 4.0 technologies has positioned them in a superior position compared to their competitors. By implementing modular and efficient automation systems that are strengthened by data-driven input, companies can usher in a new era of manufacturing and delivery. This allows them complete control over the flow of supplies and materials. The advantages of Industry 4.0 include enhanced performance and competitiveness, increased adaptability and resilience, and greater profitability.

Moreover, Industry 4.0 would enhance customer service. While Smart Factory technology is captivating and thrilling, it is essential to prioritize the advantages of Industry 4.0 in every conversation. This encompasses advancements in robotics, machine-to-machine communication, retail production, and decision-making. Industry 4.0 technology enables producers to produce superior and more efficient products. This can enhance productivity and efficiency while enhancing the capital's affordability and reliability (Javaid et al., 2022). Industry 4.0 encompasses a collection of technologies, and it is crucial to comprehend each component.

Table 1: Description of Industry 4.0 Technologies

Industry 4.0 Technology	Description
3D printing/ Additive manufacturing	In additive manufacturing, materials are typically joined one layer at a time to produce 3D-printed items. This facilitates mass customization and production on demand and aids in waste reduction. Another benefit of producing goods close to eventual clients is increased supply chain adaptability. (Abdullah et al., 2023).
Artificial Intelligence	Artificial Intelligence (AI) is a critical enabler of Industry 4.0,

	empowering machines to perform complex tasks and make intelligent decisions. Machine learning algorithms enable machines to learn from data and adapt their behavior accordingly. Through pattern recognition and predictive modeling, AI can identify anomalies, optimize processes, and enable autonomous decision-making. AI-powered systems can analyze vast datasets in real-time, identifying patterns that would be impossible for humans to detect and providing actionable insights for improved operational efficiency (Ahmed et al., 2022).
Augmented and virtual reality	A fascinating new technique for integrating Computer-Generated Imagery (CGI) into the actual world is augmented reality and virtual reality. Industrial augmented and virtual reality overlays digital information over a plant worker's actual field of view using specialized goggles, glasses, or smartphone apps, increasing productivity, efficiency, and safety. Augmented reality aims to improve human performance by providing information specific to a particular task. (Abdullah et al., 2023).
Autonomous and collaborative robot	Utilizing autonomous and collaborative robots in commercial and everyday situations is becoming more popular. To develop industrial processes (glueing, coating, laser-based procedures, precision assembly, and fiber material processing), the electronics, food, logistics, and life sciences industries will need advanced robot technology. (Abdullah et al., 2023).
Autonomous vehicles	The advanced automation and opportunities offered by cutting-edge technology have elevated ordinary vehicles to the intelligent vehicle, which works autonomously with the help of the Internet of Things. These autonomous vehicles have eased workers' workload and enhanced workplace safety. These vehicles are embedded with sensing the environment, self-navigating features, connecting and communicating on the internet, obeying the traffic guidelines while ensuring the safety of passengers, pedestrians, and surroundings, making quick decisions, and self-parking. (Parekh et al., 2022).
Big data analytics	It is described as a vast quantity of heterogeneous data entering from numerous sources in different forms and conveying in real-time. This technology and method demonstrate how businesses can get a competitive edge by finding, handling, and analyzing enormous amounts of various data. (Abdullah et al., 2023).
Cloud computing/ manufacturing	defined as a service-focused company model for cloud-based resource and capability sharing in the industry. Companies can benefit from cloud-based manufacturing by using cloud-based software, a web-based management dashboard, and cloud-based collaboration. It makes it easier to combine scattered resources and build a scalable, shared platform for production sites and services across a large area. (Abdullah et al., 2023).
Cyber-physical systems	The technical description of a cyber-physical system is "systems of collaborating computational entities intimately linked to the physical world and its operations, while concurrently supplying and consuming web-based data-access and data-processing activities." Distributed manufacturing systems with cyber-physical system capabilities provide various benefits for efficient and adaptable manufacturing. (Abdullah et al., 2023).
Cybersecurity	Cybersecurity identifies, stops, prevents, and reacts to cyberattacks. The addition of the word "cyber", a new concept for high information security, is expanded to cover industrial Internet of Things situations. Cybersecurity technologies encompass tools for detecting, identifying, and preventing data loss (Abdullah et al., 2023).
Digitalization	Digitization is defined as employing digital innovations to develop a business framework, provide new revenue streams, and create value-

	producing opportunities in industrial ecosystems. In several ways, digitization influences all dimensions of an organization, such as value creation, value capture, and value delivery. (Mostaghel et al., 2022).
Internet of things	The Internet of Things enables objects to communicate, work together on projects, and make real-time choices. It builds a network of both objects and people. IoT applications in manufacturing systems decrease the scope of product recalls, early fault detection, redesign of products, and efficiency of manufacturing processes (Abdullah et al., 2023).
Machine-to-machine communication	Machine-to-machine communication is the next generation of the internet revolution in which machines communicate, send messages, receive instructions, and provide feedback to other machines without interacting with humans. This dimension has increased efficiency manifold and enabled round-the-clock functions, eliminating human limitations. (Mazhar et al., 2022).
Mixed reality	To improve user engagement with computers, a visual technique called mixed reality aims to combine the actual and virtual worlds. Therefore, mixed reality intends to blend digital technology and procedures with the actual environment, improving the user's interaction with various computing functions (Sahija, 2022).
Mobile systems and devices	Mobile systems and devices play a crucial role in Industry 4.0, enabling connectivity and facilitating real-time data exchange. Integrating mobile technologies, such as smartphones, tablets, and Internet of Things devices, empowers workers to access information, monitor processes, and control machinery remotely, which enhances flexibility, efficiency, and productivity in manufacturing environments. Mobile devices have been identified as a critical enabler of real-time data collection and analysis, allowing for improved decision-making and predictive maintenance. (Cai et al., 2022; Fragapane et al., 2022).
Radiofrequency identification (RFID)	The bar codes have been used for a long time but have "line of sight" restrictions and strict human-machine interference. The system employs a radio frequency identification system to identify a target item through a transceiver system and an electronic tag to overcome these limitations. RFID has a variety of uses, including tracking shipments, reading employee ID cards, and identifying vehicles. RFID tags will soon be used in billions of products Noman et al., 2022).
Self-healing materials	The comprehensive properties of self-healing materials substantially impact structural and polymeric components' damage detection and healing behavior. Self-healing composite materials can autonomously repair themselves after detecting damage, thus minimizing monetary losses (Kumar et al., 2023).
Simulation	Simulation technology facilitates a production system's design, implementation, testing, and real-time control. Simulated modeling can cut costs, speed development, and improve product quality(Abdullah et al., 2023).
Smart sensors	Advancements in the sensors have developed smart sensors that identify changes, measure variation, collect data, and send it to the desired address for processing and further action (Adamo et al., 2022).
System Integration	System integration involves amalgamating different subsystems or components into a more extensive system that functions as a unified entity. Software solutions refer to the process of linking different IT services, systems, and/or software to ensure they are all functionally compatible (Karri Lehtonen, 2022).

2 Methodology

2.1 Research Design

This study aims to explore the technologies of Industry 4.0 in the aviation industry, which makes it exploratory research. For this purpose, quantitative data was used in two phases of research. During the first phase, secondary data was collected through a systematic literature review from previously published articles till 2023. In the second phase, quantitative data was gathered through a questionnaire from experts in the field. Sample Population. The population of the study is the aviation industry, as it is one of the highly technology-dependent industries (Runiewicz-Wardyn, 2022). The sample population consists of the Middle East and Pakistan airlines. There are seventeen airlines in this region, and the primary data was collected from their engineering department managers as this department mainly interacts with technology. The selection of airlines from a region is sufficient as all the civil airlines have to follow the safety and airline procedures as per the "Standard and Recommended Practices" (SARPs) provided by the "International Civil Aviation Organization" (ICAO) as per the Chicago Convention 1944 as the population size is seventeen so a sample size of sixteen is required for the study (Sekaran & Bougie, 2016). Furthermore, the appropriate size of subjects for the Delphi technique is between ten to fifteen (Lange et al., 2020), and according to (Shang, 2023), the majority of studies have used fifteen to twenty subjects for the Delphi Technique, which is a sufficient size for the research. The unit of observation was the aviation field experts working in the airline industry, whereas the unit of analysis was the aviation industry.

2.2 Data Collection

The data was collected in two steps. The first step included collecting and organizing secondary data from published articles. Data from articles published from 2016 to 2023 were utilized for the study. The results of Nara et al. (2020) were used for technologies related to Industry 4.0 from 2016 to 2020. The Scopus database was also used for the extensive and exhaustive systematic literature evaluation using the key search term "Industry 4.0 technologies" to find high-quality papers from 2021 to 2023. Initially, 211 articles were found and scrutinized, and only those with more than ten citations were Kept, reducing the number of articles to 63. Furthermore, only those articles that discussed at least one Industry 4.0 technology were considered. The final sample includes 22 articles, as shown in Table 2, combined with results from previous literature. Once the technologies were identified for Industry 4.0, then their relevance in the aviation industry was determined by a questionnaire adopted from (Nara et al., 2020) determining the importance of the technology on the Likert scale of 5 (1 being "least important" and 5 being "most important") from the experts in the aviation field working in the airline industry. The data gathered is cross-sectional as it is collected at a single point in time.

Table 2: Key Technologies for the Development of Industry 4.0

Technologies	(Boyes et al., 2018)	(Cao et al., 2017)	(Chen et al., 2017)	(Dalenogare et al., 2018)	(Frank et al., 2019)	(Ghobakhloo, 2018)	Hofmann et al. (2017	(Ivanov et al., 2019)	(Kamble et al., 2018)	(Kang et al., 2016)	(Li, 2018)	(Li et al., 2017)	(Longo et al., 2017)	(Lu, 2017)	(Moeuf et al., 2018)	(Müller et al., 2018)	(Oesterreich and Teuteberg, 2016)	(Posada et al., 2015)	(Qi and Tao., 2018)	(Qin et al. (2016)	(Rojko, 2017)	(Roy et al., 2016)	(Tao et al., 2017)	(Tao and Zhang, 2017)	(Thoben et. al., 2017)	(Wan et al., 2016)	(Wollschlaeger et al., 2017)	(1u et al., 2018)	(Zawadzki et al., 2016)	(Zezulka et al., 2016)	(Zheng et al., 2018)	(Zhong et al., 2017)	(Jamwal et al., 2021)	(Hopkins 2021)	(Hassoun et al., 2022)	(Duman et al., 2021)	(Raji et al., 2021)	(Maria et al., 2021)	(Chiarini 2021)	(Soni et al., 2022)	(Ali et al., 2021)	(Gebhardt et al., 2022)	(Han et al., 2022)	(Strandhagen et al., 2022)	(Kumar et al., 2022)	(Narula et al., 2021)	(Ghobakhloo et al., 2022)	(Ammar et al., 2021)	(Nota et al., 2021)	(Jabbour et al., 2022)	(Moosavi et al., 2021)	(Elthymiou et al., 2021)	(Coelho et al., 2021)	(Molinaro et al., 2022)
Avg Citations	102	104	173	120	106	202	304	105	167	375	142	183	102	547	143	132	210	252	157	232	103	106	109	174	218	284	449	340	104	111	116	433	83	67	38	32	29	28	28	24	24	23	23	21	19	16	15	14	13	12	12	12	12	11
3D printing																																			x	x																		
Additive manufacturing			x	x	x			x	x	x	x				x	x	x												x		x																							
Artificial Intelligence		x		x							x		x					x					x						x		x		x	x	x				x														x	
Augmented and virtual reality				x	x			x	x	x			x		x		x				x	x							x		x					x																	x	
Autonomous and collaborative robot		x		x	x			x			x				x		x	x		x	x	x		x	x	x							x	x	x		x																	
Autonomous vehicles																																	x																						
Big data analytics	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	x	x		x		x		x			x			x							
Cloud computing	x	x	x	x	x			x	x	x	x		x		x	x	x	x	x		x	x	x	x	x	x	x				x	x			x						x			x										
Cloud manufacturing																																	x																						
Cyber-physical systems	x	x	x		x	x		x	x		x		x		x	x	x		x	x	x	x	x	x	x	x		x	x	x	x		x																					
Cybersecurity									x						x				x		x	x											x																					
Digitalization and virtualization		x	x					x			x						x				x			x	x	x							x	x	x	x			x	x			x	x	x	x	x		x			x	
Industrial Internet	x		x	x	x								x		x	x	x				x		x	x	x	x	x																											
Internet of things	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x		x				x						x		x			x	x		x	x
Machine-to-machine communication	x	x		x	x			x					x		x	x							x				x																											
Mixed reality																																																					x	
Mobile systems and devices	x	x	x		x			x			x	x	x				x				x	x	x		x	x	x				x																						x	
Radiofrequency identification																																	x																					
Self-healing materials																																																					x	
Simulation			x	x	x			x	x				x		x		x		x				x	x							x																							
Smart sensors	x	x	x	x	x			x		x			x				x		x		x			x	x	x	x		x		x				x	x			x		x												
System Integration		x		x	x	x							x						x												x																							

2.3 Data Analysis

The primary data collected was analyzed using the Fuzzy Delphi technique. The fuzzy integration with the traditional Delphi method had overcome the limitations, such as (1) feasible inference values that were required to be extracted from the initial response of the experts for semantic structure and quality-orientated response analysis. (2) The effect caused by the feedback in the traditional Delphi technique was required to be removed to acquire non-converged and natural results. (3) The repetitive surveys tend to reduce the response rate from the experts. (4) Overall, there is an increase in time, and the survey becomes more costly (Ishikawa et al., 1993). Furthermore, the Fuzzy Delphi technique offers many advantages, including attaining the opinion of the experts in the field, building consensus, determining the appropriateness of executing interventions, forecasting trends, and interacting with desired experts without the constraint of time and space. Additionally, this technique depends on qualified specialists, thus guaranteeing the legitimacy of data (Ciptono et al., 2019).

3 Results

The collected results were electronically tabulated on the spreadsheet, and the Fuzzy Delphi technique was used, as it was formed to apply the Fuzzy theory to semantic variables to solve the ambiguity-related responses of the experts in the Delphi method (Lange et al., 2020). This method weighs the highest and lowest points of the gathered data as endpoints of fuzzy triangle numbers. The geometric mean is considered a degree of association between these numbers to derive the statistical effect and prevent the impact of extreme values. Equation 1 serves as the operationalization of the approach (Pajković et al., 2022).

$$Gi = (Ui- Li)+(Mi-Li)/ 3 + Li \qquad (1)$$

Gi is the consensus value among the experts, Li is the minimum value, Ui is the maximum value, and Mi is the geometric mean of the answers. There are two vital elements to the fuzzy Delphi approach. First, triangular fuzzy numbers are created from each expert's comments to show the degree of agreement for each question. The defuzzification technique was then used to calculate a figure reflecting the agreement level among the responders. The construction of a linguistic variable is assisted using the Likert scale. Then, triangular fuzzy numbers are created using the linguistic variables, and to calculate the average score of fuzzy numbers, the ranking for each variable according to the experts' opinions was established through defuzzification. The scales applied in this research are shown in Table 3 (Dapari et al., 2017).

Table 3: Fuzzy Triangulation Scale

Consent Level	Fuzzy Scale		
5	0.6	0.8	1
4	0.4	0.6	0.8
3	0.2	0.4	0.6
2	0	0.2	0.4
1	0	0	0.2

Table 4 presents the final ranking of technologies on Industry 4.0 in the aviation industry.

Table 4: Ranking of Technologies and Average Fuzzy Number

Item Name	Average of Fuzzy Number	Ranking
Digitization	0.675	1
Artificial intelligence	0.671	2
Machine-to-machine communication	0.663	3
System Integration	0.663	4
Smart sensors	0.650	5

Cyber security	0.600	6
Simulation	0.600	7
Mobile systems and devices	0.583	8
Internet of thing	0.575	9
Cyber-physical system	0.563	10
Autonomous vehicles	0.550	11
Big data analytics	0.538	12
Cloud computing	0.533	13
Mixed reality	0.525	14
Self-healing materials	0.517	15
Augmented and virtual reality	0.496	16
Radiofrequency identification	0.442	17
Autonomous and collaborative robots	0.396	18
3D printing / additive manufacturing	0.379	19

The consensus value of the experts varied from 0.379 for 3D printing/ additive manufacturing to 0.675 for digitization. The criterion used in this study as a threshold to select an item was an α-cuts value of 0.5. The value of 0.5 represented the middle (median) of the range [0, 1] (Dapari et al., 2017; Nara et al., 2020); therefore, the technologies with a consensus value of more than 0.5 would only be considered as the legitimate variables for Industry 4.0 in the aviation industry. This shows that out of 19 technologies, experts have a positive consensus on 15 technologies. These technologies concerning ranking are digitization, artificial intelligence, machine-to-machine communication, System Integration, smart sensors, cyber-security, simulation, mobile systems and devices, Internet of things, cyber-physical systems, autonomous vehicles, big data analytics, cloud computing, mixed reality, and self-healing materials.

4 Discussion

This study aimed to identify the relevant technologies of Industry 4.0 for the aviation industry. The result shows that till now, there are a total of 19 technologies which had been identified as industry 4.0. These technologies have significance in diverse fields, and each industry has its relevant technologies (Bednarz et al., 2023; De Assis Dornelles et al., 2022; Maria & Devi, 2022; Nara et al., 2020). This requires identifying the most relevant technology in the field of interest. This study opened a new dimension of Industry 4.0 by steering it towards the aviation industry. The study identified that augmented and virtual reality, radio frequency identification, autonomous and collaborative robots, and 3D printing / additive manufacturing do not have much relevance in the aviation industry as their score depicts the values of 0.496, 0.442, 0.396, and 0.379, respectively, which is below the threshold of 0.5. Furthermore, digitization has been identified as the most relevant technology in industry 4.0 in the aviation industry with the highest score of 0.675; this was followed by artificial intelligence with a score of 0.671, then machine-to-machine communication and system integration displayed their relevance with a score of 0.663, smart sensors followed with a score of 0.650, cyber security secured 0.600, simulation score is 0.600, mobile system and devices at 0.583, Internet of thing scored 0.575, the cyber-physical system at 0.563, autonomous vehicles scored 0.550, big data analytics 0.538, cloud computing 0.533, mixed reality 0.525, and finally self-healing materials scored 0.517 in fuzzy Delphi method of analysis.

4.1 Practical Implication and Limitations

As this exploratory study has opened the new domain of Industry 4.0, its implications will be manifold. First, this study will act as the foundation of future research in the aviation field regarding Industry 4.0, and researchers can develop a theoretical model based on this study. Second, it can guide the professionals working in the aviation industry about the most relevant technology, and particular emphasis on these may be placed on achieving excellence and

competitive advantage. Furthermore, training new employees on the most pertinent technologies will assist in enhancing operational efficiency and enhancing productivity. An organization cannot reap the benefits of advanced technology until their workers fully understand the concept and are fully trained on that system; thus, training employees on the relevant technologies will be another vital utilization of this study.

Additionally, maintenance practices are also poised to benefit from Industry 4.0 technologies. Predictive maintenance, enabled by the Internet of Things, smart sensors, and data analytics, can detect potential equipment failures in real time, allowing for proactive maintenance and minimizing aircraft downtime. Artificial intelligence algorithms can analyze vast amounts of maintenance data, identifying patterns and anomalies to optimize maintenance schedules and improve reliability. In the realm of operations, Industry 4.0 technologies can enhance operational efficiency and safety. Artificial intelligence-powered algorithms can optimize flight routes, considering various factors such as weather conditions and fuel consumption. Real-time monitoring of aircraft systems through the Internet of Things smart sensors allows for early detection of anomalies and immediate action. Additionally, simulations and mobile technologies can enhance pilot training and improve situational awareness. Passenger experience is another area where Industry 4.0 innovations can significantly impact. From self-service kiosks and biometric identification to personalized in-flight entertainment and intelligent cabin management systems, integrating the Internet of Things, artificial intelligence, and data analytics can enhance passenger satisfaction, improve operational efficiency, and increase revenue opportunities. This exploratory research will serve as a foundation for further studies and discussions on applying Industry 4.0 in aviation. As the aviation industry continues to evolve, embracing Industry 4.0 principles can drive innovation, improve operational efficiency, and enhance the overall aviation ecosystem.

The researcher faced no limitations during this study.

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