



Aviation Supply Chain Management In Pakistan: Current Structure, Challenges, Resilience, And Way Forward

Umama Arshad¹, Dr. Muhammad Nazim²

¹ Department of Management Sciences, Institute of Business, Management and Administrative Sciences, Faculty of Management Sciences and Commerce, The Islamia University of Bahawalpur, Bahawalpur (Punjab), Pakistan

Email: umamaarshad713@gmail.com

² Department of Project and Operations Management, Institute of Business, Management and Administrative Sciences, Faculty of Management Sciences and Commerce, The Islamia University of Bahawalpur, Bahawalpur (Punjab), Pakistan

Email: muhammad.nazim@iub.edu.pk

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Corresponding author:

Umama Arshad

Email:

umamaarshad713@gmail.com

ABSTRACT

Aviation operations depend on highly interconnected supply networks through which aircraft, engines, spare parts, maintenance services, aviation fuel, airport infrastructure, ground services, information, finance, and regulatory approvals must be coordinated reliably and efficiently. This review critically examines the current state of Aviation Supply Chain Management (ASCM) in Pakistan, focusing on its structure, major components, operational capabilities, vulnerabilities, resilience, and future development needs. Drawing on peer-reviewed aviation and supply chain literature alongside authoritative institutional and industry evidence, the review finds that Pakistan possesses a functioning but unevenly integrated aviation supply chain comprising airlines, airports, maintenance organizations, fuel suppliers, cargo operators, ground handlers, regulators, logistics providers, financial institutions, and international suppliers. Important domestic capabilities exist in airport operations, line and base maintenance, selected technical services, cargo handling, ground operations, training, customs facilitation, and aviation-fuel distribution. Nevertheless, the system remains substantially dependent on international aircraft and engine manufacturers, lessors, specialist maintenance providers, technology vendors, and suppliers of high-value certified components and spare parts. These dependencies increase exposure to foreign-exchange constraints, long procurement lead times, supplier concentration, global logistics disruptions, fuel-price volatility, regulatory requirements, and aircraft-on-ground risks. The review further identifies fragmented information flows, uneven digital maturity, infrastructure limitations, workforce constraints, and limited end-to-end supply chain coordination as important barriers to efficiency and resilience. It argues that Pakistan's principal ASCM challenge lies not in the absence of individual aviation functions, but in insufficient integration, visibility, redundancy, and strategic coordination across the wider ecosystem. Priority areas include strategic procurement, supplier diversification, improved inventory planning, selective MRO localization, cargo infrastructure modernization, interoperable digital systems, workforce development, resilience planning, and sustainability-oriented supply chain practices. The review provides an integrated Pakistan-centric ASCM framework and proposes a focused research, managerial, and policy agenda for developing a more resilient, technologically capable, and competitive aviation supply chain ecosystem.

Introduction

Air transport is at the same time a transport service and the product of a sophisticated industrial-service supply chain. A flight that is scheduled can only depart when there is an air worthy jet, trained crew, fuel, certified parts, maintenance support, airport capacity, ground services, security clearance, digital information, and money settlement. This interdependence has been more prominent as the demand for global aviation has bounced back from COVID-19 and aircraft and engine delivery delays, maintenance capacity constraints and parts shortages continue. According to IATA, global passenger demand grew by 5.3% in 2025 and the aerospace supply-chain constraints are a significant issue for the airline industry, estimated at over US\$11 billion in industry costs (International Air Transport Association [IATA], 2026a). In 2025, global air cargo demand also peaked, with a 3.4% increase compared to the previous year, highlighting the aviation sector's ongoing critical function in time-sensitive trade and supply chains (IATA, 2026b).

For developing aviation markets, these are global factors that are of particular concern. In such markets, airlines may be using aircraft designed and built overseas, financing aircraft with foreign currency, obtaining certified parts from supplier networks that are concentrated overseas, and relying on repair facilities overseas for certain engines and components. Airports also rely on dedicated security systems, baggage handling facilities, airfield technology, airport information systems and ground support equipment. Disruptions to the supply-chain thus rapidly cascade into aircraft on ground events, schedule disruption, cost escalation, and loss of connectivity. The literature on supply chain resilience has a strong focus on responses to such exposure, such as visibility, flexibility, redundancy, information sharing and recovery capability (Brandon-Jones et al., 2014; Christopher & Peck, 2004; Ponomarev & Holcomb, 2009). Unusually rigorous safety, traceability and airworthiness requirements are placed on aviation, limiting substitution and ruling out alternatives that are not 'cheaper' or locally available unless they meet approved technical and regulatory standards.

Pakistan is an important case study to analyse these dynamics. The country has a vast population, a considerable number of expatriates, industrial concentration, geographically spread domestic markets and trade ties with the Gulf, South Asian countries, China, Europe and other countries. While civil aviation passenger traffic climbed from 12.8 million in FY2006-07 to 24.3 million in FY2024-25, the growth is uneven, with the CCP noting higher rates of growth in international traffic relative to domestic traffic and identifying structural issues of domestic traffic stagnation, airline financial fragility, underutilized airports, limited aviation-specific finance, fragmented aviation governance, and reliance on Gulf connectivity (CCP, 2026). These trends indicate that airlines' profits and passenger traffic at airports are not the only ways to measure aviation-performance. It should also be appreciated along the supply chains that make the fleet available, maintainable, fuelable, cargo-processable, procurable, financeable and regulatory compliant.

Institutional changes have recently occurred, rendering a review of the supply chain especially timely. Since bifurcation, the functional separation has been implemented, as reflected in the aeronautical information publications of Pakistan Airports Authority (PAA) (2026), the Pakistan Civil Aviation Authority (PCAA) and Pakistan Airports Authority (PAA) now exist as legally separate entities under the Pakistan Civil Aviation Act (2023a) and Pakistan Airports Authority Act (2023b). Recently, the State handed over the control of the management of PIACL to the investor consortium, after the first financial closing of the privatization deal (Press Information Department [PID], 2026). While these changes may have an impact on airport investment, airline procurement, supplier governance and performance management, their implications for the supply-chain have not been studied empirically.

Evidence to support Pakistan is sometimes inconsistent. There is limited peer-reviewed research directly related to integrated aviation supply chain management in Pakistan, and valuable information exists in government publications and technical pages of companies, in tenders records, in aviation regulations and information in airports, at international aviation bodies, and in general aviation supply chain research. The approach for this review is therefore critical integrative and not necessarily a formal systematic-review protocol. Evidence is chosen for its relevance, authority, recentness, and usefulness in explaining aviation supply-chain structures and decisions. The method has purposefully identified three groups: existing practice in Pakistan that is documented; emerging practice, for which there is limited evidence; and future practice, for which there is some indication of value based on international research. The distinction is relevant for technologies like artificial intelligence (AI), blockchain, digital twins, predictive maintenance, and sustainable aviation fuel (SAF), which have a high interest globally and a low level of evidence of implementation in Pakistan.

This central review question is: What is the current state of Aviation Supply Chain Management in Pakistan; in terms of its components, structure, practices, capabilities, challenges, vulnerabilities, resilience, and future development needs? There are

four goals to the review. Firstly, it conceptualises ASCM and charts out the Upstream, Core, Supporting, and Downstream actors in the aviation supply chain of Pakistan. Second, it takes an in-depth look at interdependent major component chains – such as airlines, airports, MRO, spare parts, fuel, cargo, ground handling, catering, and procurement. Third, it combines economic, regulatory, technological, human-capital and disruption-related constraints. Fourth, it creates a realistic research and policy agenda for Pakistan and not for merely transferring high income hub practices. The contribution is an integrated perspective of a sector that is discussed and managed as organisational silos, but whose operational performance is essentially networked.

Aviation Supply Chain Management: Conceptual Background

The supply chain management (SCM) is the management of interorganizational flows and relationships that create and deliver value, not only the optimization of the logistics function of a single firm (Mentzer et al., 2001). In aviation, ASCM represents the totality of organisations providing the physical equipments, consumables, infrastructures, technical services, information, financial resources and regulatory certainty that is necessary for the safety and reliability of air transport. It is thus wider than airline management, which focuses on carrier strategy and operations; wider than airport management, which focuses on airport infrastructure and service delivery; and wider than aviation logistics or air cargo, which mainly focuses on the transport and handling of goods. Aerospace manufacturing is an upstream component of ASCM but ASCM extends well beyond aircraft manufacture, including leasing, operation, maintenance, component replacement, repair, remarketing and finally withdrawal.

There are five flow types that are analytically useful, and they are related to each other. This encompasses aircraft, engines, rotables, repairables, consumables, lubricants, Jet-A1, catering material, ground support equipment, security equipment and airport spares. These pieces of information include flight schedules, technical logs, reliability data, inventory balances, maintenance records, supplier documents, passenger data, cargo status messages, procurement records and customs documents. Financial flows include those for aircraft lease, supplier payments, MRO invoices, fuel payments, airport charges, insurance premiums and foreign-currency settlement. Service flows encompass passenger and cargo transportation, maintenance, refueling, catering, ground handling, airport operations, training and logistics. Finally, regulatory flows are airworthiness approvals, maintenance-organization certification, customs release, security controls, dangerous-goods requirements, licensing and safety oversight. Disruption in one flow can stall the other – for example, the physical spare may arrive in Pakistan, but cannot be put to use until traceability paperwork is finished, customs clearance is secured, payment is made, and airworthiness acceptance is completed.

There are also differences between aviation supply chains and many consumer-product supply chains, with the critical needs for safety affecting the selection of suppliers and the policy for holding inventory. There are various stocking, repair-loop and pooling decisions which are commonly made by dividing parts into high-value rotables, repairables, expendables and consumables. Due to the availability of the aircraft, there are high incentives to maintain buffer inventories, and many of the components have high unit values and intermittent and slow demand. This creates a traditional service level/carrying cost trade-off, accentuated by obsolescence, fleet heterogeneity, and long replenishment time. In addition, studies on aircraft-parts traceability have shown that inventory management cannot be separated from the 'Provenance and Maintenance History' of the aircraft-parts since their airworthiness relies on the reliability of life-cycle records (Ho et al., 2021).

The review takes an integrated theoretical perspective and does not rely on one theory only. The need to coordinate the flow of material, information, and decision making across organizational boundaries is due to supply-chain integration. The resource-based view and dynamic-capability logic are useful because engineering know-how, certified facilities, supplier relationships, capabilities to handle data, and skilled personnel can be hard to replicate resources in aviation. In line with resilience theory, focus should be placed on preparing for disruption, responding to it, recovering from it, and adapting to it; an empirical study has linked information sharing and connectivity to supply-chain visibility and resilience (Brandon-Jones et al., 2014). Institutional theory is very relevant in Pakistan as in various aspects of the economy, organizational decisions are influenced by regulation, public procurement rules, customs practices, ownership forms and government policy. Transaction-cost reasoning can be used to account for the choices of airlines to internalize some services, such as line maintenance or ground handling, but outsource engine and component work, which is infrequent or capital-intensive.

These views coalesce in a simple statement: Pakistan's aviation performance is not only about the numbers of aviation assets, but about the ability to coordinate inter-dependent resources – within regulatory and economic limits. Thus, the ASCM system must be resilient in physical capacity as well as the co-ordinating capability. The concept used throughout this article assigns the aircraft and engine manufacturers, as well as lessors, parts suppliers, fuel suppliers, technology providers, equipment manufacturers and caterers to the upstream side of the business; airlines, airports, MRO providers and cargo operators to the

core; and passengers, cargo customers, exporters, importers and businesses to the downstream side. The core is surrounded by regulators, customs, ground handlers, freight forwarders, banks, insurers, security organisations and training institutions as enabling or constraining actors. Material, information, financial, service and regulatory flows are not sequential but happen across all layers.

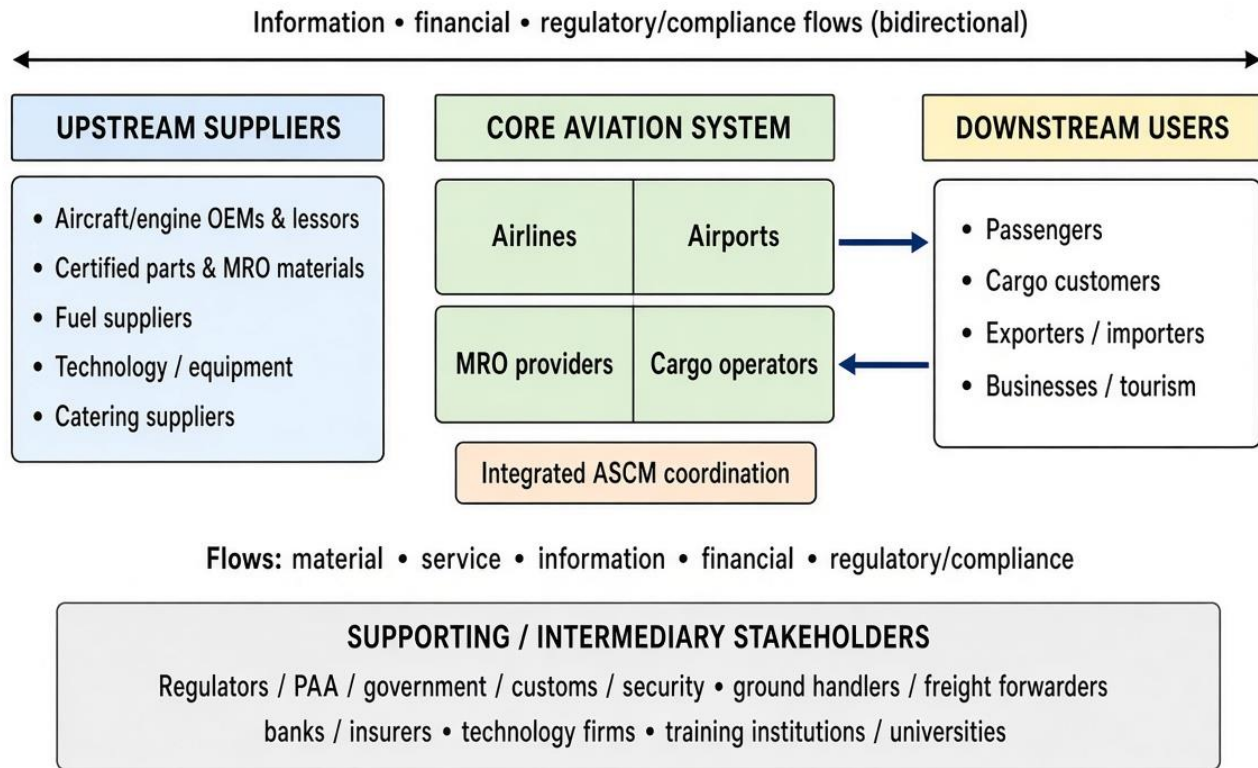


Figure 1. Conceptual Framework of Aviation Supply Chain Management in Pakistan

Table 1. Major Components of Aviation Supply Chain Management

Component	Main activities	Key stakeholders	Supply-chain significance
Fleet and aircraft acquisition	Purchase/leasing, fleet planning, induction, financing	Airlines, OEMs, lessors, banks, PCAA	Determines capacity, technology, maintenance and foreign-currency exposure
MRO and technical support	Line/base maintenance, inspection, engine/component repair	Airlines, AMOs, OEMs, specialist MROs, PCAA	Converts parts, labor and technical data into aircraft availability
Spare parts and inventory	Sourcing, pooling, stocking, repair loops, traceability	OEMs, distributors, airlines, MROs, customs	Balances serviceability against high inventory cost and long lead times
Airport operations	Terminal/airfield systems, baggage, security, utilities	PAA/SIAL, handlers, ASF, technology suppliers	Provides the physical node through which passenger, aircraft and cargo flows synchronize
Aviation fuel	Sourcing, storage, quality control, hydrant/refueler delivery	Fuel companies, refineries/importers, airports, airlines	Critical consumable; major cost and disruption exposure
Air cargo	Terminal handling, customs, warehousing, forwarding, cold chain	Airlines, freight forwarders, customs, airports, shippers	Links export/import supply chains to global time-sensitive markets
Ground handling	Ramp, baggage, towing,	Airlines, handlers, airports,	Directly affects turnaround time and

	cleaning, loading, fuelers, caterers	network punctuality
	turnaround coordination	
Catering	Sourcing, preparation, Airlines, caterers, food security, loading, suppliers, airport security	Connects service quality with food safety, cold chain and operational timing
Procurement and supplier management	waste/reverse logistics Tendering, qualification, Airlines, airport entities, contracting, payment, suppliers, PPRA/public performance monitoring bodies	Governs cost, compliance, lead time, transparency and supplier risk
Digital and data infrastructure	ERP, maintenance Airlines, airports, customs, systems, cargo systems, technology firms tracking, analytics	Enables visibility, coordination and decision speed across the network

Overview of Pakistan's Aviation Industry and Supply Chain

The aviation supply chain in Pakistan can be viewed as a hybrid public-private network with an overwhelmingly international aerospace supply base. Demand is fuelled by domestic travel, labour and diaspora migration to the Gulf and beyond, religious travel, tourism, business travel, and cargo transport. The CCP's 2026 market assessment estimates that there were 24.3 million passengers on the railways in FY2024-25, up from 12.8 million in FY2006-07, with international traffic increasing at a much faster rate than domestic traffic during this period (CCP, 2026). This asymmetry is supply-chain relevant: it makes the importance and relevance of international airport capacity, foreign airline interfaces, cross-border payment arrangements, international ground and cargo standards, and reliable connectivity with the Gulf hubs all the more salient.

However, on the airline main line, PIA is the biggest integrated airline of Pakistan so far. The Pakistan Economic Survey shows that its fleet was 31 aircraft in 2025, it transported 3.791 million revenue passengers, its passenger load factor was 82%, its operating revenue was around Rs211.7 billion, and it transported over 38,000 tonnes of cargo for which it collected around Rs10.5 billion of revenue (Finance Division, 2026). Since the European restriction was lifted in January 2025, PIA resumed its service to Paris while in October 2025 it restarted operations to Manchester, UK, expanding the carrier's supplier and service interfaces (Finance Division, 2026). The transfer to private management in June 2026 is a potentially important movement in the procurement incentives, capital allocation, fleet strategy and supplier governance (PID, 2026). The active scheduled operations by private airlines such as airblue, AirSial and Fly Jinnah are confirmed on airline websites; of note is the fact that Fly Jinnah's network for 2026 encompasses both domestic destinations and services to the Gulf markets. But, standardized fleet and supply-chain data for the private airlines are still limited (Airblue, n.d.; AirSial, n.d.; Fly Jinnah, n.d.).

There is a number of key nodes in the airport network that have various roles in the supply chain. Karachi, Lahore and Islamabad are the main international air gateways and also the centers of the highest airline, maintenance, fuel, cargo, ground-handling, customs and passenger services. Important regional, labour market, export and diaspora flows are with Peshawar, Quetta, Multan and Sialkot. The PAA eAIP for 2026 will document the existing national aerodrome system, the updated aerodrome data of Islamabad, Peshawar, Quetta, Turbat and other airports (PAA, 2026). Sialkot is institutionally unique since Sialkot International Airport Limited labels it as Pakistan's privately owned international airport and maintains a separate cargo complex which is connected to a large export manufacturing zone (Sialkot International Airport Limited [SIAL], n.d.-a).

Supply-chain governance is a key factor in the 2023 bifurcation of institutions. PCAA is now the civil aviation regulatory arm while PAA is responsible for the airport and aeronautical-information functions and the Air Safety Investigation Act, 2023, strengthened the statutory basis for safety investigation (Government of Pakistan 2023a, 2023b, 2023c). This kind of separation can help to clarify roles, however, effective ASCM needs coordination between aviation regulators, airport operators, the Ministry of Defence, customs and tax authorities, Airport Security Force, immigration, public procurement bodies, airlines and private suppliers. The CCP's vision of an integrated national aviation strategy, a unified aviation data hub, digital slot allocation, and a more coherent financing and airport-commercial policies indicates that institutional separation has not per se resolved the cross-agency coordination issues (CCP, 2026).

Pakistan has also had some significant technical and logistics capacities. The documents provided by PIA Engineering include line and base maintenance, four hangars and maintenance capability for Boeing 777 and the Airbus A320 family, which have been approved by the Pakistan Civil Aviation Authority (PIA, n.d.-b, n.d.-d). The cargo terminal in Sialkot is expected to handle 20,000 tonnes of cargo annually and features automated cargo handling, cold storage, scanning, warehousing, interface with customs and electronic status messaging (SIAL, n.d.-b). Pakistan Single Window is an electronic gateway for import submissions, which is

one of several examples of trade digitalization that can help eliminate documentary delays in aviation trade once it is fully embedded in trade flows (Pakistan Single Window [PSW], n.d.).

The global embeddedness in the supply chain persists. Aircraft, engines, avionics and many certified components come from international OEM ecosystems and lessors, insurers, specialist MROs, technology vendors and banks link Pakistani operators with the international financial and technical markets. Thus, the exchange-rate and remittance are not just financial but operational variables. At the end of October 2025, at US\$54 million, the amount of airline funds blocked in Pakistan was lower than in earlier periods yet still pointed to the existence of repatriation friction (IATA, 2025). From an ASCM point of view, the national system is thus a country with national operating capacity and imported technology and foreign currency-dependent support chains.

Table 2. Structure of Aviation Supply Chain Management in Pakistan

Supply-chain component	Major actors	Current characteristics	Key dependencies	Major challenges
Airlines	PIA; private Pakistani carriers; foreign airlines	Mixed ownership; narrow- and wide-body operations; strong international orientation	OEMs, lessors, global parts/MRO, airports, fuel, FX	Fleet availability, financing, supplier lead times, cost pressure
Airports	PAA airports; SIAL; service concessionaires	Karachi/Lahore/Islamabad as main gateways; regional and export-oriented nodes	Equipment suppliers, utilities, handlers, security, customs	Uneven utilization, terminal modernization, data integration
MRO	PIA Engineering; private line-maintenance firms; overseas MROs	Domestic line/base capability exists; selected complex work externally procured	OEM data, certified parts, tooling, skilled labor, foreign approvals	Engine/component depth, capex, certification, turnaround time
Parts/inventory	Airlines, MROs, OEM/distributors, customs	Safety-critical, largely imported, documentation-intensive	Hard currency, customs, traceability, global logistics	AOG risk, obsolescence, long lead times, carrying cost
Fuel	PSO and airport fuel infrastructure	PSO reports 99% Jet-A1 market share and service at about 15 major airports (PSO, n.d.-b)	Petroleum supply, storage, airport access, quality systems	Supplier concentration, price volatility, hydrant coverage
Cargo	Airlines, SIAL/PAA terminals, forwarders, customs, express firms	Belly cargo important; specialized export/cold-chain capacity exists at selected nodes	International connectivity, customs, warehouses, handling systems	Fragmented national data, dwell time, cold-chain scale, route depth
Supporting institutions	PCAA, PAA, customs/FBR, ASF, PPRA, banks, insurers, training bodies	Multi-agency governance with growing digital interfaces	Interagency coordination and information exchange	Policy consistency, financing, skills, data interoperability

Major Components of Aviation Supply Chain Management in Pakistan

Airline Supply Chains

The airline supply chain starts well before an airline publishes a flight schedule. Fleet planning involves aircraft type, lease or purchase, engine type, training needs, tooling, spares, maintenance contracts and Airport compatibility. This upstream architecture is structurally international in Pakistan as the commercial aircraft and major engines are not made in the country to the extent needed by scheduled airlines. So many of the aircraft leasing, OEM support, engine work and other many component deals are foreign currency commitments. PIA's balance of Boeing 777s and Airbus A320-family planes will require separate technical supply chains, and the vast majority of private carriers own narrow-body aircraft, which are imported planes.

Commonality of fleet can lower training and inventory complexity, while the opposite can result in higher variety of spares, engineering workload and exposure to obsolescence.

Then, the airline supply chain stretches out to fuel, catering, ground handling, airport charges, crew's logistics, IT, distribution and maintenance. As shown in PIA's current bids, procurement encompasses a wide range of services, such as food inputs, information technology equipment and support, crew hotel services, janitorial services and catering services at foreign stations; and all of such procurement is done through a formal mechanism of evaluation (PIA, n.d.-a). This illustrates the importance of not limiting ASCM to technical spares. The airline handles 'safety-critical engineering purchases', and 'service/consumable' categories that have a high frequency of purchases. The qualification, planning and financial implications are different: Where a GE90 engine shop visit calls for technical qualification, long planning periods and high financial risk, catering inputs call for quality control, cold chain, freshness and high frequency of replenishment.

PIA's privatization presents a new strategic variable. Private management can foster greater incentives for fleet productivity, working-capital discipline, supplier rationalisation, and commercial contracting, but will also bring greater focus upon governance systems that ensure safety, traceability and continuity of service during the procurement transformation process. One of the management challenges is thus to differentiate suppliers according to their criticality and not to negotiate a cost reduction across the board. Resilience and reliability can be a more important consideration than unit price for aircraft and engine support and for commodity categories, competitive tendering and consolidation may be more appropriate.

Airport Supply Chains

Airports are not infrastructure that simply sits there passively. They are the points of synchronization where aircraft, passengers, baggage, cargo, fuel, ground equipment, catering, security, customs, immigration and information systems converge. Karachi, Lahore and Islamabad are the most important strategic points as disruption in these nodes could impact national and international networks. Regional connectivity and, in a few instances, links to labour and export markets are provided by Peshawar, Quetta, Multan and Sialkot. Newer infrastructure nodes like Gwadar International Airport will only have long-term supply-chain value if there are developments in traffic, surface connectivity, depth of service providers, and commercial connections, and not just infrastructure (PAA, 2026).

The CCP highlights terminal modernization (Karachi and Lahore), utilization of secondary airports, e-gates, digital slot allocation and aviation data as policy priorities (CCP, 2026). These recommendations focus on bottlenecks in throughput and information coordination from a supply-chain perspective. Terminal or ramp constraints cause queuing and uncertainty in turnaround; weak baggage and/or passenger-processing systems can cause aircraft to delay departure; insufficient cargo storage can jeopardize perishables and insufficient systems interoperability can cause manual reconciliation. The investments in the airport supply chain should therefore not only be assessed in terms of terminal size, but also in terms of flow time, reliability, visibility and interface quality.

The example of Sialkot is a good example of a specialised airport-logistics model. Its cargo complex offers automated handling, cold- and strong-room facilities, dangerous-goods facilities, scanning, warehousing, electronic status updates and a one-stop clearance concept, among other things, with a stated design capacity of 20,000 tonnes per year (SIAL, n.d.-b). The meaning is not that Sialkot should be replicated mechanically but the concept that the supply chains of the airport could be tailored around the industrial demand within the area. There are different cargo capacity, schedule, and customs needs for export clusters of surgical instruments, sporting goods, textiles, perishables or pharmaceuticals.

MRO and Technical Supply Chains

MRO is one of the most complex functions in aviation in terms of supply chain because all the parts, labor, tooling, technical data, repairs, and certifications are all being used at once. Unlike what "import-dependent" implies, Pakistan has a good base for MROs. PIA Engineering provides 24-hour line maintenance, base maintenance in four hangars, and is approved on Boeing 777 and in the Airbus A320-family, with approvals including PCAA approval PCAA.145.001, and Saudi Arabia, Qatar, Bahrain and Oman aviation authority approvals (PIA, n.d.-b, n.d.-d). These capabilities contribute to the availability of the domestic fleet and can provide third-party services.

However, there are uneven capabilities in depth. In 2025, a PIA Supply Chain Management tender was issued for GE90-series repair/overhaul services for PIA's Boeing 777 fleet (PIA, 2025). This is in itself direct evidence that even an airline with extensive in house engineering facilities, needs outside support for highly capital intensive and OEM dependent engine work. Long lead

times are caused by engine and component repair loops where the unserviceable engine/component is removed, documented and exported or sent to an approved shop, repaired, tested, returned, cleared and reinstall. Swapping, buffers, power-by-the-hour (PBTH) and pooling can minimize on-ground exposure, but are dependent on good forecasting and liquidity.

The strategic opportunity is not autarky, it is selective localization. Pakistan will not be able to economically duplicate all the OEM capabilities. A more realistic MRO strategy would have defined the tasks that would be common to the fleet that have sufficient national and regional demand (line maintenance, selected base checks, wheels/brakes, avionics, structures, components, and carefully chosen engine modules) and then built certification, tooling and human capital around them. This way, foreign exchange outflows and turnaround times can be minimized, and access to global specialist networks can be maintained.

Aircraft Spare Parts and Inventory

Spare-parts management is a main vulnerability due to the intermittent demand, that the consequences of failure are severe, in addition to the restricted substitution. An airline's service level objectives are in conflict with the carrying cost of the valuable assets. When something is missing on an aircraft, lost revenue, disruption of passengers, recovery cost and reputation take a hit—even with a cheap inventory policy. On the other hand, too much inventory ties up valuable resources in stagnant assets and exposes them to the risk of becoming obsolete.

This optimization problem is compounded by the added elements of customs, logistics, exchange rates, and payment when Pakistan relies on import of parts. In addition, parts must have approved-source documentation and maintenance history, making traceability as much a part of the quality of parts as it is of an administrative afterthought (Ho et al., 2021). Practical priorities involve multi-echelon inventory planning for Karachi, Lahore, Islamabad and outstations; criticality and lead-time classification; rotatable pooling; repair-loop control; minimum serviceable-unit policies and AOG escalation policies. The risk of using counterfeit parts also further emphasizes the importance of approved suppliers and documentation integrity. While blockchain enable traceability has been proven globally and is a potential way to maintain trusted aircraft parts records, there is currently a lack of evidence for operational implementation of blockchain traceability in the aviation sector in Pakistan (Ho et al., 2021). It should therefore be considered as an option for the future, not as a capability of the current.

Aviation Fuel Supply Chain

Fuel is an essential part of a mission - it is a consumable and a large financial risk. Pakistan State Oil (PSO) has a national market share of 99% in Jet-A1, it provides service to about 15 major airports, has around 70 refueling vehicles and hydrant dispensers of up to 3,800 liters per minute (Pakistan State Oil [PSO], n.d.-b). Hydrant refueling is also available in Karachi, Lahore and Islamabad, and the other locations are dependent on refuelers and local storage facilities (PSO, n.d.-a). Jet-A1 is delivered to international standards, and the price for aviation is updated every 2 weeks (PSO, n.d.-a).

While this architecture is beneficial in terms of scale and quality-control, it may also present a concentration risk, if contingency measures are not put in place for supply, storage, transport and emergency replenishment. There is also the risk of airline fuel which is dependent on international oil prices, exchange rates, taxes/charges and refinery and import conditions, as well as airport inventory. For aviation-specific use, there are limited publicly available data on the aviation-specific portion of refinery production and imports of jet fuel over time because public data do not explicitly reveal the aviation-specific split. Supply-chain resilience should thus be about minimum stock policies, airport-level contingency plans, quality assurance, alternative logistics routes and transparent service level agreements, and not on national fuel availability guarantees airport-level continuity.

Air Cargo and Freight Logistics

The air-cargo is a mix of belly capacity, carrier cargo sales, airport cargo terminals, freight forwarders, customs brokers and express logistics in Pakistan. In 2025, over 38,000 tonnes of cargo was transported by PIA, and Sialkot offers an export-oriented cargo terminal featuring cold storage, dangerous-goods facilities, security scanning, warehousing, automated handling, and electronic status messaging (SIAL, n.d.-b; Finance Division, 2026). These capabilities are pertinent to products with a high value but low weight and products with time sensitivity and temperature sensitivity. They can be used for pharmaceuticals, perishables, agricultural products, textiles and apparel samples, surgical goods, electronics, express shipments and for e-commerce.

The geo-strategically significant position of Pakistan, between South Asia, Central Asia, China and Middle East, is only a potential asset. Competitive cargo hubs must boast frequent wide body connectivity, reliable customs clearance, cold-chain integrity, predictable ground handling, warehouse space, digital connectivity, and an extensive freight-forwarder ecosystem. Singapore is

an example of how the two can be found in one place: Changi's cargo model combines a free-trade-zone environment, specialist cold-chain and express services, leading cargo forwarders, automation and planned cargo/MRO industrial zones (Changi Airport Group, n.d.). This integration in Singapore could take Pakistan lessons without taking a leap towards trying to achieve the same level of integration on a larger scale.

Data is a great challenging aspect of analysis. With the exception of carrier or airport-specific data, there are few publicly available national-level consistent data on volumes of belly versus freighter traffic, the mix of goods transported, dwell times, cold-chain throughput or airport-level cargo service performance. Publicly available data on this dimension are still scarce. This will make cargo investments of higher priority difficult and should be regarded as a gap in policy and research.

Ground Handling

Ground handling turns the airport facilities into aircraft's turnaround performance. Ramp operations, baggage handling, passenger handling, towing, cleaning, loading of cargo, coordinating fueling and loading of catering must be coordinated within limited time windows. PIA represents itself as a leading ground handler in Pakistan and other airlines resort to a mix of self-handling and contracted ground handlers on per airport and per route basis (PIA, n.d.-c). Failures snowball: If baggage is not loaded on time, doors may not close; if the fuel bowser is not on time, the pushback may be delayed; if the ground support equipment fails, multiple flights may be affected; if connections in the airline network are not made then the failure may ripple through the network.

Airline Catering

Catering is another time-sensitive micro-supply chain. This starts with the supplier qualification and food sourcing, extends to preparation, halal and food-safety compliance, chilled storage, security screening, transport to the aircraft, loading, onboard service, and waste return. Reports of PIA's biddings for 2026 show that PIA has been actively involved in procurement activities, especially in the procurement of ingredients as well as in the procurement of station services, for yogurt, cream, jam/preserved fruit, meal trays, and overseas catering services (PIA, n.d.-a). The challenge for the supply-chain is to balance food safety and service level with short shelf life, varying passenger numbers, security requirements and waste reduction. Hence, cold-chain monitoring, demand forecasting, local supplier audit and reverse-logistics practices are more pertinent than negotiating reduction in meal price.

Procurement and Supplier Management

The most common way in which aviation supply-chain dependencies turn into contracts is through procurement. In the public sector in Pakistan, the Public Procurement Rules define the principles of public sector procurement, which include competitive bidding, transparency, value for money and the implementation of e-Procurement through bidding (Public Procurement Regulatory Authority [PPRA], 2021). From PIA's historical and current tender data, it can be observed that there is a formal function of Supply Chain Management (SCM), which has Technical and Financial Evaluation in Engineering, IT, Consumables, Facilities and Service categories (PIA, n.d.-a).

However, in aviation procurement, it's not just about the procedures. Supplier qualification should include aspects of airworthiness approval, quality systems, traceability, sanctions/export-control exposure as applicable, lead-time reliability, repair capability, warranty conditions, exchange/loan support, and financial viability. Public or bureaucratic tender cycles can clash with the AOG concept of urgency and, similarly, emergency procurements without proper controls can lead to higher cost and provenance risks. Thus, a mature ASCM model requires prequalified supplier panels, framework agreements, emergency procurement that is well-governed, lifecycle-cost evaluation and supplier-performance data. Payment reliability is also operationally critical as international vendors may limit credit or withhold shipment if payment is late.

Contemporary Challenges Affecting Aviation Supply Chains in Pakistan

The aviation supply-chain constraints are not independent, but complementary in Pakistan. International dependency of aircraft, engines, key components, specialized tooling, software, and many repair services is a most important structural dependency. Import dependence is not by itself inefficient, as the world's aerospace industry is focused everywhere, but together with a shortage of foreign currency, a fluctuating exchange rate, limited choice of suppliers and sluggish administration, import dependence becomes a problem. This creates a longer and more leveraged supply chain compared to airlines close to the key OEM/MRO hubs.

Foreign exchange and financial constraints are particularly significant since aviation liabilities are in US dollars or in some other hard currency while huge revenue is received in rupees. When the currency depreciates, the local-currency price of leases, parts, engine shop visits, software subscriptions and insurance all go up. Repatriation constraints were also easing but not going away – as per IATA's blocked-funds data, US\$54 million remained blocked in Pakistan by the end of October 2025 (IATA, 2025). Foreign airlines' capacity allocation may be affected by the delay in repatriation and in the case of the Pakistani Airlines, repatriation delays may affect supplier payments and procurement. Financial fragility as a result cascades into operational reliability through the supply chain.

The availability of infrastructure is not uniform. The assets of the airports in Pakistan are modern or developed in recent years, but the quality of capacity varies at nodes and in process. The CCP's recommendations for modernization at the terminals of Karachi and Lahore, the efficiency of secondary airports, the implementation of e-gates and enhanced slot and data systems reveal that the efficiency of passenger processing and the infrastructure are still issues of concern (CCP, 2026). Cargo carrying capacity is also focused. Sialkot shows specialization in handling and cold storage, but there is not much transparent information on the cold-chain capacity and cargo dwell times in all major airports. Infrastructure policy should therefore move from construction-centric metrics towards flow-centric indicators such as turnaround time, baggage performance, warehouse dwell, equipment availability and system uptime.

MRO and spare-part constraints are a mixture of technical and economic factors. While PIA's in-country engineering base is important, specialist foreign capability is still required as evidenced by the GE90 overhaul procurement. Over-Distributed Repair Loops lead to higher number of rotatables needed to ensure service-level protection. Further fragmentation of inventory is due to fleet diversity. In Pakistan, especially, a problem could be that while the optimum safety stock is worked out in physical units, it could be unaffordable when hard currency and working capital are limited. This tension can result in reactive procurement of AOG that are typically more costly than intended procurement.

There are several regulatory and institutional issues related to the fact that there are numerous organisations that could affect a single aviation transaction. Induction activities can include PCAA approval, customs clearance, financing, insurance, airport readiness and operator training. Cargo includes airlines, handlers, customs, security, freight forwarders and other government agencies. The split between regulator and airport authority is a positive structural separation in 2023, but coordination capability is still needed. Fragmented governance and policy inconsistency continue as a market issue identified by the CCP's 2026 assessment. Predictability, time-boundness, and digital connectivity of the institutional interfaces are the key supply-chain questions.

The spectrum of human capital issues ranges from the pilots to licensed aircraft maintenance engineers, avionics technicians, reliability engineers, planners, procurement experts, cargo experts, cybersecurity experts and aviation data analysts. PIA Training Centre provides training courses for Boeing 777, A320-family, ATR, GE90, structures and other engineering, which is a proof of the domestic training base (PIA, n.d.-e). However, no national data exists on vacancies, license pipelines or attrition or the specialist supply-chain skills, and the data is not routinely published. There are still limited publicly available reliable data on this dimension. Brain drain can be especially expensive as experienced Pakistani technical staff is in demand in the aviation market of the Gulf and internationally.

These problems are exacerbated by technology and data limitations. Digital distribution, digital payments, customs single window, computerized cargo handling and airline/airport systems are some of the documented instances in Pakistan. The online distribution, travel portals and digital payment systems account for more than 10% of total revenue in 2025 (Finance Division, 2026), and PSW digitises trade declarations (PSW, n.d.). But there's not much public proof of sector-wide visibility of real-time inventory, MRO information integrated with procurement data, RFID at scale, AI-driven predictive maintenance, blockchain traceability of components or digital twins. It's important because the technology story can be a distraction from the more basic needs for clean master data, process standardization, cyber security and interoperable systems.

Pakistan is also vulnerable to exogenous shocks to the global supply chains. The aviation industry is a sector that has shown its fragility in the face of a simultaneous drop in demand and operating restrictions, as happened during the COVID-19 pandemic (Belhadi et al., 2021; Suau-Sánchez et al., 2020). In more recent times, aircraft and engine supply constraints have created additional pressure on the maintenance and fleet costs (IATA, 2026a). Geopolitical conflict, airspace restrictions, energy shocks, floods, cyber incidents or supplier failures can thus interact with liquidity and infrastructure constraints. The message is that resilience is not something that can only be achieved by individual airlines, but needs to be coordinated through risk management of airports, fuel, customs, MRO, security, finance and regulators.

Table 3. Major Challenges Affecting Pakistan's Aviation Supply Chain

Challenge	Principal causes	Supply-chain impact	Most affected stakeholders	Potential response
Foreign supplier dependence	Global concentration; limited local manufacturing	Long lead times, imported inflation, AOG exposure	Airlines, MROs	Dual sourcing where approved; pooling; long-term support agreements
FX and payment constraints	Currency volatility; hard-currency availability; repatriation processes	Delayed payments, higher lease/parts/MRO cost	Airlines, foreign carriers, suppliers	FX planning, predictable repatriation, supplier credit frameworks
MRO depth gaps	High capex, certification, tooling, scale requirements	Overseas repair, longer turnaround, spare buffers	Airlines, MROs	Selective localization and regional third-party MRO strategy
Fragmented data	Organizational silos; heterogeneous systems	Weak visibility, manual reconciliation, slow decisions	Airlines, airports, regulators, customs	Shared data standards, APIs, data governance, unified indicators
Airport/process bottlenecks	Legacy terminal/process design; uneven investment	Delays, dwell time, poor utilization	Airports, airlines, passengers, cargo	Flow-based modernization; equipment reliability; digital processing
Skills constraints	Training lead times; international labor demand	Maintenance/operations bottlenecks, dependence on expatriate/vendor support	Airlines, airports, MROs	Licensing pipelines, retention, university-industry programs
Procurement rigidity/urgency tension	Formal rules versus AOG time sensitivity	Expediting cost or governance risk	Public aviation bodies, airlines	Prequalification, frameworks, governed emergency procurement
Supplier concentration	Limited approved sources; dominant fuel and OEM providers	Single-point vulnerability	Entire network	Contingency contracts, minimum stocks, alternative logistics paths

Aviation Supply Chain Resilience

Resilience involves the ability to prepare for disruption, the ability to maintain or restore critical functions as well as the ability to adapt the supply chain after the event (Christopher & Peck, 2004; Ponomarov & Holcomb, 2009). Resilience matters more for Pakistan as a number of vulnerabilities are interlinked: a currency shock can lead to fewer imports of parts; fewer parts can lead to more grounded aircraft; less capacity can lead to less revenue; less revenue can lead to less parts import. A strictly “lean” strategy that seeks to reduce buffers without taking this feedback into account can thus be financially risky even if technically it is “safe.”

COVID-19 was an example of how aviation disruptions can impact demand, capacity, workforce, airport operations, and supplier sustainability at the same time. After the outbreak of COVID-19, research in the airline industry identified business continuity, flexibility, localization when possible and digital technologies as important resilience mechanisms (Belhadi et al., 2021). Ivanov's notion of supply-chain viability introduces the notion that sometimes, organizations need to redesign their structures instead of simply going back to the state prior to the shock (Ivanov, 2022). In Pakistan, this rationale underpins the possibility of more selective changes, such as an expanded number of suppliers, local repair capacities, better cargo supply chains, and digitization of coordination, instead of merely more inventory.

Five resilience capacities seem to be especially significant. Firstly, visibility must occur throughout the inventory, repair orders, supplier lead times, airport disruptions, fuel stock and cargo status. Managers lack a common set of data and know about the disruption only after it occurs, reacting by expediting. Second, and most important, redundancy should be targeted: safety-critical rotables, fuel contingency stocks, alternate ground equipment, backup IT should have buffers, but the rest of the stock should not.

Third, flexibility is only possible with pre-approved alternate suppliers, repair shops, routes, handlers and logistics channels. Fourth, the need to work together is paramount as no airline will be able to resolve customs, fuel, airport, or regulatory issues on their own. Fifth, financial resilience (liquidity, FX planning, insurance and supplier credit) is as much about physical resilience as it is about anything else.

Localization is a sensitive topic. Internationally sourced items, catering, uniforms, packaging, some repair services and selected ground equipment, can be sourced domestically, which can cut down international lead times for items that are not safety critical. Certified aircraft parts: localization requires approved design, manufacturing, quality and regulatory systems; unauthorized substitution is not a resilience strategy. There is potential for future use of additive manufacturing in aerospace sustainment and reduction of lead times, but it is limited by approved material/process certification and economic scale (Blakey-Milner et al., 2021). Hence, the resilience goal for Pakistan has to be a hybrid network – a mix of localization of economically and technically feasible capabilities with diversification and security of the international dependencies that cannot be localized.

Table 4. Major Aviation Supply-Chain Risks and Resilience Strategies

Risk	Potential disruption	Current Pakistani vulnerability	Appropriate resilience response
FX shock/payment delay	Inability to pay lessors, MROs or parts suppliers	High international cost exposure	FX forecasting; payment prioritization; credit lines; policy predictability
Global parts/engine shortage	AOG events and schedule cuts	Long international replenishment and repair loops	Rotable pooling; exchange agreements; multi-source approval; critical buffers
Fuel disruption/price shock	Flight cancellation, tankering, cost escalation	Highly concentrated Jet-A1 supply	Airport stock policies; alternate logistics; joint fuel contingency planning
Airport/ground system failure	Turnaround and network delays	Dependence on key gateway nodes	Equipment redundancy; preventive maintenance; mutual-aid arrangements
Cyberattack/data outage	Reservation, cargo, maintenance or operational disruption	Growing digital dependence, uneven integration	Segmentation, backups, incident response, supplier cyber assurance
Natural disaster/flooding	Access, infrastructure and supply interruptions	Geographic and road-logistics exposure	Business continuity plans; alternative airports/routes; pre-positioned resources
Geopolitical/airspace disruption	Longer routes, fuel/cost increases, lost connectivity	Strong international route dependence	Route scenarios; flexible scheduling; fuel planning; commercial alliances
Skilled-workforce loss	Maintenance and operational capacity reduction	International competition for qualified personnel	Retention, succession planning, licensed training pipelines

Digital Transformation and Innovation

Digital transformation can't be measured by the use of the latest trends and technologies, but instead by operational integration. There are several documented digital capabilities in Pakistan today. Airline websites offer online booking and customer self-service; airblue refers to the shift towards cashless travelling and digital processes (Airblue, n.d.). PIA reports meaningful online-distribution and digital-payment revenue, Sialkot has computerized cargo handling and electronic status messaging, and PSW offers single-declaration interfaces for cross-border trade (Finance Division, 2026, PSW n.d., SIAL n.d.-b). These are true components of digital ASCM. The research on Industry 4.0 also highlights that the advantages of technology are heavily reliant on the integration, organizational readiness, and implementation conditions (Rad et al., 2022).

The bigger gap is the lack of end-to-end visibility across technical, procurement, logistics and regulatory systems. A good aviation control tower architecture would link fleet schedules, maintenance commitments, exposure to minimum-equipment-lists, inventory, outstanding purchase orders, repair orders, customs status, supplier performance and cash commitments. In the case of intermittent and uncertain demands, predictive analytics can be useful for enhancing demand forecasting, and in the presence

of adequate data quality and governance, AI can assist in the planning process and anomaly detection (Helo & Hao, 2022; Seyedan & Mafakheri, 2020; Toorajipour et al., 2021). However, there is no public evidence for ubiquity of AI-powered predictive maintenance in the Pakistani commercial aviation industry.

Likewise, RFID, IoT, blockchain and digital twins should be seen as opportunities. Blockchain can be used to enhance trusted parts traceability (Ho et al., 2021; Dasaklis et al., 2022) and digital twins can be used to connect physical assets with the ever-evolving virtual versions for maintenance and operations (Jones et al., 2020). However, these tools come at an implementation cost, require interoperability, pose cybersecurity risks, and raise governance issues. Let Pakistan focus on master data quality, common part numbers, e-technical record, API based customs and procurement interfaces, reliable asset tracking before embarking on complex distributed-ledger or digital-twin initiatives. The order must be digitize – integrate – analyze – automate, not the other way around.

Sustainability of Aviation Supply Chains

Aviation sustainability is a supply-chain issue because emissions and environmental impacts are "built" into the technology, fuel, energy used at airports, ground equipment, catering, procurement and end-of-life material flows. Research on climate impacts of aviation reveals the substantial impact of aviation (Gössling & Humpe, 2020), and ICAO has established CORSIA, a monitoring and offsetting framework for qualifying international operations. ICAO's CORSIA architecture provides the basis for credible monitoring and reporting of emissions by operators, while the offsetting requirements are dependent on the CORSIA rules and the State pairs involved (International Civil Aviation Organization [ICAO] n.d.-a, n.d.-b).

There is emerging evidence on sustainability in Pakistan, but it is not yet holistic. Airport and airline websites provide information on some of their digital and efficiency and environment initiatives, and reliable publicly available information on routine commercial SAF production or uplift in Pakistan remains scarce. SAF should, therefore, be viewed as a future supply-chain development, rather than an established practice domestically that needs only to be accelerated. More short-term measures include fuel efficiency initiatives, renewable airport electricity, efficient ground support equipment, waste separation, reduction of catering waste, green procurement considerations and repair/reuse of components (as long as they are still airworthy). These steps link sustainability to cost and resilience, and do not address sustainability as a standalone corporate-social-responsibility activity.

Discussion

The results from the present study suggest that undergraduate students with a visual impairment encountered a great number of pedagogical barriers when taking the Natural Sciences and Quantitative Reasoning courses. Participants especially said that classroom teaching was mainly used to present visual explanations with limited implementation of inclusive teaching practices. In the same vein, Hussain et al. (2022) identified that the visually impaired students at Pakistan's universities faced several accessibility challenges, such as low availability of Braille resources, screen reading software, audio books and other educational resources that would enable them to actively engage in university curricula and education. The study also found that lack of educational resources and accessibility provisions remained as a challenge to the academic experiences of visually impaired students, which confirmed the pedagogical barriers found in the present study. By another important finding, students had significant technological barriers, especially in the lack of access to scientific symbols, mathematical notations, diagrams, graphs and digital learning resources. The results of this study are in line with the findings of Reddy et al. (2021) who reported that students with visual impairment faced significant challenges in accessing mathematical and digital learning materials, due to limited provision and access to suitable assistive technologies. The study highlighted the importance of accessible digital tools and assistive technologies for enhancing higher education students' participation and learning outcomes, which align with the technological barriers identified in the current study. In addition, one of the most salient administrative and institutional hindrances to be found in the labs was practical learning experiences. The findings align with those of D'Agostino (2022) who noted that science instruction is heavily dependent on symbolic, spatial and visual information and that undergraduate chemistry teaching and laboratory environments are generally not accessible to blind and low vision students. The study also highlighted that the laboratory activities in science education are inaccessible for students with visual impairments and that the instructional adaptations are not sufficient to allow these students to participate in science education. The present study findings support the above findings and emphasize the importance of making lab activity and practical more accessible for universities. The study also revealed that, the students who pursue B.Ed. (Hons.) Students enrolled in Special Education programme reported significantly more pedagogical challenges and administrative/institutional barriers than compared to other undergraduate programmes. While no previous study has made a specific comparison across the different degree programmes, Firat (2021) also reported that there

were significant pedagogical and institutional barriers faced by university students with visual impairments such as inaccessible learning materials, inadequate academic support, inadequate library resources, limited awareness of the faculty, and lack of disability support services. The results of this research corroborate the current study by showing that pedagogical and institutional challenges remain to have an impact on the educational experiences of students with visual impairments in higher education. The other important result was that students who were blind had significantly more pedagogical challenges and technological barriers than students with low vision. This is similar to what Odame et al. (2021) observed, which is that graduates with visual impairments faced difficulties in accessing learning materials, not having enough assistive technologies, limited academic support, and the institution's challenges while studying at university. The study also identified that these barriers limited the engagement of the students in academic activities and negatively impacted their learning experience which corroborates the current results. Last, the results showed a significant difference between administrative/institutional barriers in the various fields of study. This result is corroborated by Moríña and Orozco (2021), who found that disabled students had an unequal kind of education depending on the context of the university because the measures of institutional support, access, and teaching were executed in an inconsistent way in the different contexts. Their findings highlight the need to enhance institutional policies and to ensure that disability support is equally adequate in multiple academic disciplines, to ensure equitable access to higher education. The findings, overall, support that undergraduate students with visual impairments still face significant pedagogical, technological, and administrative/institutional barriers when taking Natural Sciences and Quantitative Reasoning courses. A number of measures must be taken to overcome these obstacles, including the use of inclusive teaching methods, the use of learning resources and technologies which are accessible to students with visual impairments, making improvements to the accessibility of laboratories, and the strengthening of institutional support systems for the equitable participation and academic success of students with visual impairments in higher education.

Conclusion

This paper reveals that undergraduate students with visual impairments who are taking Natural Sciences and Quantitative Reasoning courses often encounter significant pedagogical, technological, and administrative/ institutional barriers, with a few instances of teacher assistance and institutional accommodation, however, they are used to the reliance on inaccessible visual instruction, un adapted laboratory activities, and inaccessible scientific symbols and digital resources. It was identified that students with a visual impairment had some access to the course content, however most of these students continued to experience limitations of following classroom instruction that relies on visual materials, and limited access to practical or assessment-oriented activities, indicating that these courses are not fully accessible to students with a visual impairment. The results also suggest that there is a significant variation in the perceptions of these barriers by degree program, type of visual impairment, and field of study and that experiences with accessibility are affected by overlapping individual and academic factors and vary across all students, but not by gender, institution type, or age. In sum, although formal policy frameworks like the HEC Undergraduate Policy 2023 are essential, the creation of accessible pedagogical practices, appropriate AT, and context-specific institutional implementation mechanisms are crucial toward ensuring the equitable academic participation of undergraduate students with visual impairments in higher education.

Recommendations

1. The pedagogical obstacle was visually oriented explanations, which should be accompanied by detailed explanations in words by instructors.
2. Institutions should implement accessible assessment methods (screen readable papers, oral exams, extended time) to address inaccessible assessment methods.
3. Universities need to dedicate resources to the development of assistive technologies which can faithfully display scientific and mathematical notation for students.
4. Digital materials (diagrams, graphs, charts, library resources) should be made accessible (tactile and screen-reader).
5. The procedures to be followed in the laboratory should be re-designed with the aid of tactile equipment, and trained assistants, so that visually impaired students can participate independently.
6. Dedicated disability support offices and accountability mechanisms should be established as part of accessibility policies, such as the HEC Undergraduate Policy 2023.

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