Supplier Risk Assessment and Strategic Response in Aerospace Supply Chains

Pascal Olivier Becher | 202427056

Dissertation submitted for the degree of Master in

Aeronautical Maintenance Engineering and Management

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I. Acknowledgements

I would like to express my sincere gratitude to my dissertation supervisor, Professor Fernando Romana, for his guidance, support, and constructive feedback throughout the development of this dissertation. I am also grateful to Atlântica – Instituto Universitário and the Master's program in Aeronautical Maintenance Engineering and Management for providing the academic environment in which this research was conducted. Furthermore, I would like to thank all industry professionals who contributed their time and expertise by participating in my survey, as their practical insights were valuable for the empirical part of this thesis. Finally, I would like to thank my family and friends for their continued encouragement, patience, and support during the preparation of this dissertation.

II. Abstract

Aerospace supply chains are complex, globally distributed, and highly dependent on specialized suppliers, long lead times, certified components, and coordinated flows between manufacturing and maintenance-related supply environments. Recent disruptions have shown that supplier-related risks can affect not only production continuity and assembly flow, but also spare-parts availability, repair turnaround, aircraft downtime, and service continuity in Maintenance, Repair and Overhaul (MRO) contexts. Therefore, supplier risk in aerospace cannot be treated only as a procurement or delivery issue, but must be assessed in relation to the operational consequences that disruption may create.

The aim of this dissertation is to develop a structured supplier-risk and strategic-response framework that supports aerospace organizations in assessing supplier-related risks and selecting feasible mitigation responses across manufacturing and MRO-related critical supply environments. The research addresses the gap that supplier-risk assessment, mitigation strategies, localization or regionalization, digital transformation, and MRO continuity are often discussed as related but separate themes. To address this gap, the dissertation combines a literature-based analysis with an empirical expert survey. The literature review establishes the conceptual and sector-specific foundation, while the survey collects practical input on disruption exposure, supplier-risk perception, assessment criteria, mitigation strategies, localization and regionalization options, digital tools, and implementation barriers.

The findings show that supplier risk in aerospace is multi-dimensional. Important vulnerability areas include capacity risk, geopolitical or location exposure, single-source dependency, logistics and lead-time risk, quality and certification constraints, and spare-parts or repair-network dependency. The results also indicate that supplier-risk assessment should combine several criteria, including component criticality, supplier lead time, availability of alternative suppliers, quality performance, delivery reliability, visibility, certification dependency, and MRO relevance. The empirical findings further suggest that strategies such as dual or multiple sourcing, supplier diversification, contingency planning, strategic partnerships, and buffer inventory are perceived as more realistic in practice than more structural or technology-dependent responses such as full localization, additive manufacturing, or advanced digital monitoring. Because the survey sample is limited, the empirical results are not treated as statistically representative, but as structured expert input for framework development.

The main contribution of this dissertation is the proposed supplier-risk and strategic-response framework. The framework links supplier-risk profile, consequence domain, response matching, feasibility evaluation, and strategic decision output. It supports the view that aerospace resilience should not rely on one universal mitigation strategy, but on a conditional decision logic that connects assessed risks with operational consequences and feasible response options. The framework therefore provides a practical decision-support structure for strengthening resilience in aerospace manufacturing and MRO-related supply environments.

Keywords: Supplier Risk Assessment; Strategic Response; Aerospace Supply Chains; MRO; Supply Chain Resilience; Localization; Digital Transformation

III. Resumo

As cadeias de abastecimento aeroespaciais são sistemas complexos, multinível e globalmente distribuídos, dependentes de fornecedores especializados, componentes certificados, prazos de entrega longos, requisitos rigorosos de qualidade e fluxos coordenados entre fabrico, logística, operadores e manutenção. Esta estrutura permite beneficiar de capacidades tecnológicas avançadas e economias de escala, mas aumenta a interdependência entre atores e a exposição a disrupções. Um problema num fornecedor crítico, numa região geopoliticamente exposta, numa rota logística ou num processo de certificação pode afetar a continuidade da produção, o fluxo de montagem, a disponibilidade de peças sobressalentes, os tempos de reparação, o risco de Aircraft-on-Ground (AOG) e a continuidade do serviço em Maintenance, Repair and Overhaul (MRO). Assim, o risco de fornecedores no setor aeroespacial não deve ser entendido apenas como uma questão de compra, preço ou entrega, mas como um problema operacional que deve ser avaliado em função das consequências que pode gerar no fabrico, no MRO ou em ambos os domínios.

O objetivo desta dissertação é desenvolver um modelo estruturado de avaliação de risco de fornecedores e de resposta estratégica que apoie organizações aeroespaciais na identificação de riscos associados a fornecedores e na seleção de respostas de mitigação viáveis em ambientes críticos de abastecimento ligados ao fabrico e ao MRO. A questão central de investigação é: como podem as organizações aeroespaciais avaliar riscos associados a fornecedores e selecionar respostas estratégicas viáveis para reforçar a resiliência em ambientes críticos de abastecimento relacionados com fabrico e MRO? A investigação aborda uma lacuna de integração: avaliação de risco de fornecedores, mitigação, localização ou regionalização, transformação digital e continuidade do MRO são frequentemente discutidas como áreas relacionadas, mas separadas. A dissertação propõe, por isso, uma lógica de decisão que relaciona perfil de risco, consequência operacional, resposta estratégica e viabilidade prática.

A revisão da literatura estabelece a base conceptual e setorial do estudo. Clarifica conceitos como disrupção, vulnerabilidade, exposição, resiliência, robustez, agilidade, flexibilidade e resposta estratégica, tratando a resiliência como capacidade dinâmica de antecipar, responder, recuperar e adaptar a cadeia perante perturbações. A dissertação analisa também a estrutura multinível das cadeias aeroespaciais, a especialização tecnológica, os requisitos de certificação e qualidade, a substituibilidade limitada de componentes e a interdependência entre fabricantes, fornecedores, operadores e redes de manutenção. Estes fatores tornam o setor sensível a atrasos, restrições de capacidade, falhas de qualidade, dependência de fornecedor único, limitações de aprovação e falta de visibilidade a montante.

A dissertação diferencia dois domínios de abastecimento interligados, mas não idênticos: o fabrico de aeronaves e o MRO. No fabrico, uma disrupção de fornecedor pode afetar a continuidade da produção, a montagem final, a coordenação de pacotes de trabalho, a estabilidade de programas e o cumprimento de calendários industriais. No MRO, as consequências estão mais ligadas à disponibilidade da aeronave, à existência de peças aprovadas, à capacidade de reparação, ao turnaround time, à prevenção de AOG e à continuidade do serviço. Esta distinção é essencial porque uma mesma categoria de risco pode exigir respostas diferentes conforme o impacto principal seja produtivo, operacional ou combinado. Disrupções como COVID-19, conflitos geopolíticos, sanções, escassez de matérias-primas e estrangulamentos logísticos revelaram fragilidades de cadeias globais orientadas para eficiência, concentração de fornecedores e níveis reduzidos de stock. O desafio é equilibrar eficiência e resiliência sem comprometer a continuidade operacional.

A parte empírica foi realizada através de um inquérito online dirigido a profissionais com exposição prática a cadeias de abastecimento aeroespaciais. O inquérito recolheu 16 respostas e foi analisado como contributo especializado de natureza descritiva, não como evidência estatisticamente representativa de todo o setor. A amostra incluiu profissionais de supply chain e logística, procurement e sourcing, consultoria, qualidade ou desenvolvimento de fornecedores, MRO e outras funções relacionadas. O questionário abordou perfil dos respondentes, exposição a disrupções, perceção de riscos, critérios e métodos de avaliação, mitigação, localização e regionalização, ferramentas digitais, barreiras de adoção e comentários abertos.

Os resultados confirmam que o risco de fornecedores no setor aeroespacial é multidimensional. Entre os fatores de disrupção recentes, destacam-se conflito geopolítico e sanções, restrições de capacidade dos fornecedores, disrupções pandémicas, estrangulamentos logísticos e restrições regulatórias ou de certificação. As categorias de risco relevantes incluem riscos logísticos e de lead time, riscos operacionais, qualidade, capacidade, finanças, informação e visibilidade, dependência de fornecedor único, dependência de peças sobressalentes ou redes de reparação, exposição geopolítica e restrições de certificação. As vulnerabilidades mais críticas foram capacidade, exposição geopolítica ou geográfica e dependência de fornecedor único. As consequências mais importantes foram atraso de produção, aumento de custos, AOG, interrupção de montagem e riscos de qualidade ou conformidade.

Os resultados relativos à avaliação de risco mostram que as organizações aeroespaciais devem usar uma lógica multicritério, em vez de depender apenas de preço, desempenho de entrega ou scorecards gerais. Os critérios mais relevantes incluem fiabilidade de entrega, lead time, fornecedores alternativos, qualidade, criticidade do componente, visibilidade, apoio a peças sobressalentes ou reparação, certificação, estabilidade financeira e exposição geográfica. A maioria dos respondentes indicou que utiliza métodos estruturados ou parcialmente estruturados. As abordagens mais úteis foram ferramentas digitais ou analíticas preditivas, modelos multicritério, combinação de métodos e scorecards.

Quanto às estratégias de mitigação, os resultados mostram uma diferença entre eficácia percebida e realismo prático. Parcerias estratégicas, diversificação, planeamento de contingência, dupla ou múltipla fonte, monitorização digital, inventário de reserva e posicionamento de peças críticas foram considerados relevantes. Porém, as respostas vistas como mais realistas foram dupla ou múltipla fonte, diversificação, planeamento de contingência, parcerias estratégicas e inventário de reserva. Em contraste, localização ou regionalização, fabrico aditivo e algumas ferramentas digitais avançadas foram percecionados como menos imediatamente realistas. Isto sugere que respostas integráveis em estruturas existentes de procurement, gestão de fornecedores e planeamento operacional são mais viáveis a curto prazo, enquanto respostas estruturais ou tecnológicas exigem análise de custos, certificação, capacidade, maturidade de dados e recursos internos.

A análise de localização, regionalização e digitalização reforça esta lógica condicional. Os respondentes concordaram que a localização pode reduzir exposição geopolítica e riscos de lead time, e reconheceram que a regionalização de apoio MRO ou de capacidade de peças sobressalentes pode reforçar a resiliência mesmo quando a produção permanece global. No entanto, a diversificação foi frequentemente considerada mais realista do que a localização completa, devido a custos, escala, capacidades industriais, certificação e limitações do ecossistema aeroespacial. A localização ou regionalização parece mais justificada para componentes críticos, itens de lead time longo, peças com elevado impacto de downtime, itens geopoliticamente expostos e capacidade de reparação próxima de bases ou hubs de MRO. Ferramentas digitais como visibilidade em tempo real, análise de fornecedores, IA, blockchain, rastreabilidade, manutenção preditiva, gémeos digitais e fabrico aditivo são suporte, não soluções automáticas.

Com base na literatura e nos resultados empíricos, a dissertação propõe um modelo de avaliação de risco de fornecedores e resposta estratégica composto por cinco etapas. A primeira define o perfil de risco do fornecedor ou item, considerando criticidade, lead time, exposição de capacidade, risco de qualidade, dependência de certificação, exposição geográfica, fornecedores alternativos, visibilidade e relevância para MRO. A segunda identifica o domínio de consequência, distinguindo continuidade do fabrico, continuidade do serviço MRO ou ambos. A terceira liga o risco e a consequência a respostas possíveis, como diversificação, dupla fonte, desenvolvimento de fornecedores, parcerias estratégicas, inventário de reserva, posicionamento de peças críticas, avaliação da rede de reparação, regionalização, nearshoring, monitorização digital, rastreabilidade ou localização seletiva. A quarta aplica um filtro de viabilidade baseado em custo, certificação, capacidade regional,

escala, aprovação, dados, esforço de implementação e adequação ao negócio. A quinta produz uma decisão estratégica sob a forma de pacote de ações e lógica de revisão contínua.

A principal contribuição da dissertação é integrar avaliação de risco, consequência operacional, resposta estratégica e viabilidade prática numa lógica de decisão específica para cadeias de abastecimento aeroespaciais. O modelo evita tratar a avaliação de fornecedores como simples pontuação isolada e evita apresentar estratégias de mitigação como lista genérica. Em vez disso, considera que uma resposta só é adequada quando corresponde ao risco identificado, ao impacto esperado e às condições reais de implementação. Conclui-se que a resiliência aeroespacial não depende de uma única medida dominante, como localização, digitalização, inventário adicional ou diversificação, mas da ligação disciplinada entre avaliação estruturada, consequência operacional, resposta viável e revisão contínua. A principal limitação do estudo é a dimensão reduzida da amostra, pelo que investigação futura poderá validar o modelo com amostras maiores, estudos de caso empresariais e aplicações separadas em fabrico e MRO.

Palavras-chave: Avaliação de Risco de Fornecedores; Resposta Estratégica; Cadeias de Abastecimento Aeroespaciais; MRO; Resiliência da Cadeia de Abastecimento; Localização; Transformação Digital

IV. Index

V. List of Tables and Figures

VI. List of Abbreviations

AC	Advisory Circular
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AIMS	Adaptive Inventory Management System
AM	Additive Manufacturing
AOG	Aircraft on Ground
ARJ21	Advanced Regional Jet, Comac C909
BMW	Bayerische Motoren Werke (Bavarian Motor Works)
D	Detection
E2E	End to End
FAA	Federal Aviation Administration
FMEA	Failure Mode and Effects Analysis
ICT	Information and Communication Technology
IoT	Internet of Things
JIT	Just-In-Time
LLM	Large Language Models
MADM	Multi-Attribute Decision Making
MFT	Multi-Functional Teams
ML	Machine Learning
MRO	Maintenance, Repair, Overhaul
NC	Numerical Control
NDA	Non-Disclosure Agreement
O	Occurrence
OEM	Original Equipment Manufacturer
PMA	Parts Manufacturer Approval
Q	Question

R&D	Research and Development
RFI	Requests for Information
RFID	Radio-Frequency Identification
RFP	Requests for Proposal
RFTI	Requests for Technical Information
RPN	Risk Priority Number
S	Severity
SCM	Supply Chain Management
SCRM	Supply Chain Risk Management
SME	Small and Medium-sized Enterprise
SWOT	Strengths, Weaknesses, Opportunities, Threats

Figure 1

Airbus A320-Family Final Assembly Line

Note. Reprinted from A321XLR in assembly line [Photograph], by Airbus Operations GmbH, 2021, Airbus Media Centre. Copyright 2022 by Airbus Operations GmbH.

Figure 2

Air Berlin Technik Hangar

Note. Source: Author's own photograph, taken at the Air Berlin Technik hangar in 2014.

VII. Report

1. Introduction

Aerospace supply chains operate as complex, globally distributed networks rather than simple linear procurement systems. They depend on specialized suppliers, international sourcing structures, and coordinated flows of materials, information, and services. (Shih, 2018) These structures allow aerospace organizations to benefit from specialization, economies of scale, and advanced supplier capabilities, but they also increase interdependence and exposure to disruption across wider supply networks. (Okoye et al., 2024) Recent crises have shown that disruptions are not limited to temporary delivery problems. In aviation-related supply chains, the COVID-19 pandemic and the wider post-pandemic disruption environment revealed structural vulnerabilities across aircraft manufacturing, spare-parts supply, airline logistics, and maintenance support. (Syed, 2025)

This dissertation focuses on supplier-risk assessment and strategic response in aerospace manufacturing and MRO-related supply environments. This combined perspective is necessary because manufacturing and maintenance-related supply chains are connected, but they do not create the same disruption consequences. In this dissertation, aircraft manufacturing is treated as a supply environment in which supplier disruption can affect production continuity, assembly flow, work-package coordination, and program stability. MRO-related supply environments are treated as contexts in which supplier disruption can affect spare-parts availability, repair turnaround, aircraft downtime, Aircraft-on-Ground risk, and service continuity. Therefore, supplier risk in aerospace cannot be assessed only as a procurement or delivery issue. It must be understood in relation to the operational consequence that a disruption would create in the specific supply environment.

The aim of this dissertation is to develop a structured supplier-risk and strategic-response framework that supports aerospace organizations in assessing supplier-related risks and selecting feasible mitigation responses across manufacturing and MRO-related critical supply environments. The central research question is: How can aerospace organizations assess supplier-related risks and select feasible strategic responses to strengthen resilience across manufacturing and MRO-related critical supply environments? This dissertation addresses the gap that supplier risk, mitigation strategies, localization, digital transformation, and MRO continuity are often discussed as related but separate themes. The focus of this dissertation is therefore to integrate these themes into one aerospace-specific decision logic that connects supplier-risk profiles with operational consequences, response selection, and feasibility conditions.

To address this gap, the dissertation first develops a literature-based foundation on supply chain resilience, aerospace supply-chain structure, manufacturing and MRO supply environments, disruption exposure, supplier risks, assessment approaches, mitigation strategies, localization and regionalization, and digital transformation. This is followed by an empirical expert survey that collects practical input on supplier-risk perception, assessment criteria, mitigation strategies, localization or regionalization options, digital tools, and implementation barriers. Based on the literature review and empirical findings, the dissertation develops a supplier-risk and strategic-response framework that links risk assessment, consequence domain, response matching, and feasibility evaluation. Chapter 2 reviews the relevant literature, Chapter 3 explains the methodology, Chapter 4 presents the empirical findings, Chapter 5 discusses the findings and develops the framework, and Chapter 6 concludes with recommendations.

2. Literature Review

2.1. Foundations of Supply Chain Resilience, Risk, and Strategic Response

2.1.1. Supply Chains and Supply Networks as Interconnected Systems

Supply chains should not be understood as simple linear sequences that move materials from supplier to producer and then to customer. Rather, they are interconnected systems composed of organizations, people, resources, activities, and information flows that together transform raw materials and services into final products and services. The structure of a supply chain is shaped by strategic decisions regarding what a firm performs internally and what it procures externally, including make-or-buy choices, outsourcing decisions, and location choices. As a result, supply chains are better understood as networks rather than as isolated transactional chains. (Shih, 2018)

This networked structure creates important economic advantages. Specialization allows suppliers to build deeper technological capabilities, benefit from scale effects, and serve multiple customers more efficiently than a single focal firm could achieve alone. However, these same structures also increase interdependence. As supply networks become more global and more tiered, downstream firms, which are positioned closer to final assembly or the end customer often have only limited visibility into higher-tier suppliers further upstream in the network, including suppliers of suppliers and subcontracted production nodes. In such environments, risks are not confined to the direct supplier relationship; they may emerge several tiers upstream and still affect the focal firm's performance. (Shih, 2018)

The implications of this are significant for resilience research. Globalization has increased efficiency, market reach, and sourcing flexibility, but it has also intensified systemic vulnerability by lengthening supply networks and increasing dependence across firms and regions. Interconnectedness means that a disruption in one location can generate ripple effects across the wider network, affecting actors that may have no direct contractual relationship with the original source of disruption. This is why supply chain analysis must extend beyond firm-level procurement logic and consider the broader supply network in which production, sourcing, logistics, and information exchange are embedded. (Okoye et al., 2024)

This network perspective is especially relevant for aerospace-related settings, where resilience increasingly depends on end-to-end visibility, collaboration across multiple actors, and the ability to understand dependencies beyond immediate suppliers. Even at this conceptual stage, it is therefore necessary to frame supply chains as interconnected systems in which structural complexity, limited visibility, and cross-tier dependence shape later questions of vulnerability, disruption, and strategic response. (Syed, 2025)

2.1.2. Supply Chain Disruption, Vulnerability, and Exposure

Supply chain disruption can be understood as an event or set of events that interrupts the expected flow of materials, information, or services across a supply network. The literature shows that such disturbances may arise from natural disasters, geopolitical instability, supplier disruptions, or other forms of cross-border uncertainty. Vulnerability, however, is not the disruption itself. Rather, it describes how easily a supply network can be harmed when such a disruption occurs. Exposure, in turn, describes the degree to which a firm is placed in a position where it can be affected by a disruption. In other words, it refers to how closely a company is linked to the disrupted supplier, region, transport route, or supply activity, and therefore how likely it is that the disruption will affect its own operations. (Okoye et al., 2024)

This distinction matters because highly globalized and efficiency-oriented supply chains are not affected by shocks in a uniform way; their degree of vulnerability depends on sourcing concentration, information visibility, and the capacity to absorb disruption. Evidence from pandemic-related risk studies shows that disruptions rarely remain isolated. Instead, they spread through multiple linked problem areas, including shortages on supply markets, bullwhip effects, loss of key suppliers, transportation breakdowns, government restrictions, supplier temporary closure, market demand change, and single sourcing. Where information sharing is weak and firms depend on limited sources or restricted transport channels, exposure becomes significantly more severe. (Ghadir et al., 2022)

The relevance of disruption, vulnerability, and exposure becomes even clearer in aviation-related supply chains. In that context, the COVID-19 outbreak did not merely create temporary delays, but revealed inherent structural weaknesses across aircraft manufacturing, airport management, airline logistics, and aircraft-parts supply at the same time. The shock therefore exposed how strongly aviation systems depended on continuous flows, stable supplier networks, and synchronized planning. The subsequent shift from cost-efficient and lean aviation designs toward more agile, redundant, and end-to-end-visibility-based models suggests that disruption is analytically important not only because it causes damage, but because it reveals where the system is structurally fragile. (Syed, 2025)

Vulnerability is also shaped by preparedness. Where contingency planning and supplier collaboration are weak, even a manageable disturbance can escalate into a broader supply problem. Evidence showing limited contingency-plan coverage and limited collaborative processes with suppliers therefore supports the view that exposure is not only embedded in network structure, but also in the extent to which firms are organizationally prepared for disruption. (Romana et al., 2023)

2.1.3. Resilience, Robustness, Agility, and Flexibility

Resilience is one of the central concepts in this dissertation, but it should not be treated as interchangeable with related terms such as robustness, agility, and flexibility. In the recent literature, resilience increasingly refers to more than simple resistance to disturbance. Rather, it describes a broader capability through which supply chains anticipate disruptions, respond to them, recover from them, and adapt their structures where necessary. (Holloway, 2025)

This broader understanding is also reflected in recent aviation resilience research, which points to a shift from reactive responses toward more proactive supply chain models. (Syed, 2025)

Robustness is closely related to resilience, but it is narrower in meaning. It refers to the ability of a supply chain to continue functioning when exposed to disruption, that is, to withstand shocks without immediate collapse or major performance loss. Resilience, by contrast, goes further because it also includes recovery and adaptation after the disturbance has occurred. In that sense, robustness can be understood as one important component of resilience, but not as a complete substitute for it. This distinction is also reflected in aviation-related evidence, where digitally enabled supply chains demonstrated not only “more robust disruption recovery” but also stronger adaptive performance after crisis conditions. (Syed, 2025)

Flexibility and agility represent related but distinct dimensions of supply chain response. Flexibility refers to the ability of a supply chain to adjust how it operates when conditions change, for example by altering lead times, order configurations, inventory positioning, or available capacity. Shih’s framework reflects this logic clearly: firms supplying innovative products tend to compete “more on speed and flexibility,” while the main challenge in a responsive supply chain is “reducing lead times and increasing the flexibility to change the mix or configuration of orders.” (Shih, 2018) In practical terms, flexibility therefore depends on the existence of adjustment options within the system, such as strategic inventory buffers, late customization, and excess capacity at key bottlenecks. (Shih, 2018)

Agility, by contrast, places greater emphasis on the speed with which a supply chain can react. It is not only about having response options available, but about activating them quickly enough to manage disruption effectively. The recent technology-oriented resilience literature links agility to the ability to build “more resilient and agile supply chains” that can better anticipate, respond to, and recover from disruption under conditions of uncertainty. (Holloway, 2025) In aviation, this distinction becomes especially visible in the post-pandemic context, where organizations using AI-driven analytics, IoT (Internet of Things)-

based monitoring, digital-twin simulations, and blockchain-enabled traceability demonstrated "stronger agility, higher operational responsiveness, and more robust disruption recovery" than fragmented and traditionally managed networks. (Syed, 2025)

Taken together, these concepts overlap, but they should not be treated as identical. Flexibility concerns the presence of adjustment possibilities within the supply chain. (Shih, 2018) Agility, by contrast, concerns the speed with which those possibilities can be translated into action. Resilience is the broader capability that integrates these response qualities within a more adaptive system. Recent literature increasingly describes resilient supply chains as dynamic and adaptive rather than static structures. (Holloway, 2025) In aviation, this broader resilience is strengthened when digital capabilities, operational integration, and process redesign are combined rather than treated in isolation. (Syed, 2025)

2.1.4. Supply Chain Risk and Strategic Response

Supply chain risk should not be understood as a narrow operational issue. The extracted literature shows that global supply chains are exposed to a wide range of threats, including natural disasters, geopolitical instability, supplier disruptions, and cybersecurity threats. Because international supply chains are increasingly complex and interconnected, the effective management of these risks becomes crucial for maintaining resilience and continuity in global trade. (Okoye et al., 2024)

Strategic response, therefore, requires more than isolated reactions after disruption has already occurred. The literature emphasizes that supply chain risk management strategies are needed to eliminate or mitigate the effects of disruptions in global sourcing and manufacturing. It also suggests that strategic response must remain adaptive, since "Emerging trends in global supply chain risk management encompass technological advancements and changing geopolitical dynamics." (Okoye et al., 2024) In the same vein, the extracted material points to continuous risk assessment, scenario planning, agile and flexible supply chain structures, the integration of risk management into strategic decision-making processes, and the cultivation of strong partnerships across the supply chain ecosystem as important elements of a stronger response architecture. (Okoye et al., 2024)

In aviation, the relationship between supply chain risk and strategic response becomes especially visible in the post-pandemic restructuring of supply chains. The extracted evidence shows that different aviation regions adopted different resilience strategies depending on their infrastructure maturity, regulatory environments, and technological readiness. North America and Europe placed stronger emphasis on digital automation, predictive analytics, and sustainability-focused reforms, whereas Asia-Pacific relied more heavily on localization, multi-tier supplier models, and flexible sourcing. Emerging regions, in turn, concentrated more on digital enablement, capacity building, and visibility tools. These patterns indicate that strategic response is context-specific rather than universal. (Syed, 2025)

A further implication is that strategic response depends heavily on coordination across actors. The extracted aviation literature shows that public-private partnerships, integrated supplier ecosystems, and data-sharing consortia contributed to stabilizing aviation operations during and after disruption. On that basis, future-ready aviation supply chains are shaped not by one single mitigation lever, but by the combined effect of digital technologies, multi-stakeholder governance, and broader system-level coordination. (Syed, 2025)

2.1.5. The Efficiency–Resilience Trade-Off

One side of the trade-off is rooted in the long-standing pressure to reduce costs and improve flow. As one extracted source notes, during the 1980s organizations were increasingly driven by the need to provide “lower costs” together with higher quality and greater variety. (Romana et al., 2023) In that context, “Just in time (little stock and flexible production according to demand), the Kaizen methodology (eliminating waste), among others” contributed to lower stock levels and improved logistical flow. (Romana et al., 2023)

In aviation-related supply chains, however, the cost logic cannot be separated from readiness and continuity requirements. Cathay Pacific's internal formulation captures this balance directly: "Inventory management for Cathay Pacific is determining the right quantity of spare parts and material at the right time and at the right place to meet anticipated and unanticipated demands to maintain aircraft operations at the desired service level at the optimal costs." (Yen, 2009) Yet the same extracted material also states that, "To guard against the risk and cost of prolonged downtime, Cathay Pacific normally built in a buffer stock," even though this created additional cost. (Yen, 2009) A similar tension appears in military aviation, where inventory management must "keep costs as low as practical while maintaining the level of readiness necessary for completing the mission," and where shortages can create Aircraft-on-Ground (AOG) situations that force urgent sourcing at much higher cost. (Al-Momani et al., 2020)

The trade-off therefore does not lie in choosing either efficiency or resilience in absolute terms, but in deciding how far supply chains can be optimized for low inventory, low holding cost, and lean flow before operational continuity is put at risk. The post-pandemic aviation context illustrates how this balance has shifted. One extracted passage states that airlines "transformed conventional Just-In-Time models through multi-supplier contracts on essential parts," while MRO vendors strengthened coordination with OEMs (Original Equipment Manufacturers) and suppliers on "lead times, maintenance windows and inventory buffering." (Syed, 2025) In that sense, resilience-oriented strategic response does not reject efficiency altogether; rather, it recalibrates sourcing, inventory, and coordination choices when lean arrangements become too fragile under disruption. (Syed, 2025)

2.2. Structural Characteristics of Aerospace Supply Chains

2.2.1. Complexity and Multi-Tier Structure in Aerospace Supply Chains

Aerospace supply chains are characterized by a deep multi-tier structure rather than by a simple chain of direct suppliers. Aircraft manufacturing is supported by an "extensive, deep and multi-tired supplier base," with major first-tier suppliers concentrated around aerostructures, engines, and avionics. (Horng, 2006) Because the number of qualified suppliers is limited by high capital requirements and demanding technological capabilities, different aerospace manufacturers often depend on the same upper-tier suppliers, which creates strong interdependencies across the industry. (Horng, 2006)

This structural depth has become even more pronounced as major aircraft programs shifted away from earlier purchasing models toward more externally distributed program architectures. In the case of the A350 XWB and the 787 Dreamliner, Airbus and Boeing introduced new supply chain strategies that created "some of the most complex and extended supply chains in industrial history." (Wendt, 2016) At the same time, older build-to-print subcontracting relationships—which is, arrangements in which suppliers mainly manufactured components to designs specified by the aircraft manufacturer rather than assuming broader design responsibility—have increasingly been replaced by internationally devolved design and engineering tasks, which means that complexity in aerospace is not limited to the number of firms involved, but also includes the dispersion of development responsibility across the network. (Pritchard & MacPherson, 2007)

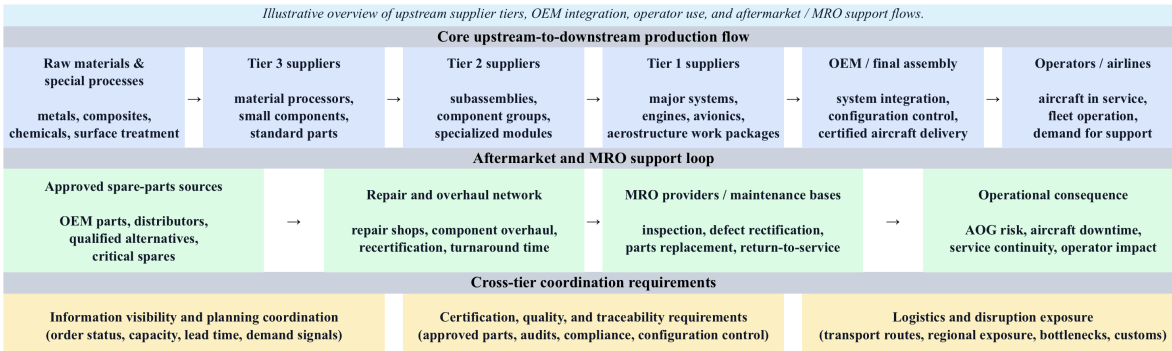
Within this structure, the OEM increasingly operates as an architect and system integrator rather than as a fully vertically integrated manufacturer. Airbus, for example, keeps its most strategic competences internal, yet around 70% of the cost of an aircraft is purchased externally, and the company works almost exclusively with first-tier full suppliers that are responsible for the development, financing, and production of complete sub-systems. In strategically important areas, Airbus also relies on pivot firms, meaning first-tier strategic partners that combine the competences required for the design and development of specific sub-assemblies and coordinate their integration with the wider aircraft system, while jointly specifying interfaces and assuming coordination responsibilities for the relevant sub-assemblies. The hierarchy of aerospace supply chains therefore reflects not only layered sourcing, but also the transfer of significant design, development, and coordination tasks to external partners. (Mazaud, 2019)

The structure is also highly international. Large aerospace clusters typically consist of one or several OEMs surrounded by hundreds of smaller lower-tier firms, yet the supply chain itself is “basically international.” (Niosi & Zhegu, 2005) International knowledge and coordination linkages occur especially between Tier 1 and Tier 2 firms, while lower-tier suppliers are more locally embedded and often manufacture pieces and parts that are later transferred elsewhere for final assembly. Aerospace production is therefore simultaneously clustered and globally dispersed: final assembly may be concentrated in one region, while major parts and critical components are produced across a much wider international network. (Niosi & Zhegu, 2005)

Such multi-tier depth significantly raises coordination demands, because as more entities participate in the supplier network, the risk of delays, errors, and inefficiencies increases and makes closer coordination across multiple tiers necessary. (Horng, 2006) This challenge becomes even more acute when upstream outsourcing extends beyond the OEM’s direct line of sight: Tier-1 suppliers may pass work packages further to Tier-2 suppliers, and where those suppliers do not fully meet the required technical standards, planning uncertainty and schedule delays can quickly follow. (Wendt, 2016) Complexity in aerospace supply chains is therefore not merely an organizational background condition, but a defining structural characteristic that shapes visibility, coordination difficulty, and dependence across the production system.

Figure 3

Simplified Multi-Tier Structure of an Aerospace Supply Chain



Note. Source: Author's own illustration.

2.2.2. Certification, Regulation, and Quality Requirements

Aerospace supply chains are shaped not only by technological complexity, but also by stringent certification, regulatory, and quality requirements that narrow the range of acceptable suppliers and supply options. In aviation spare-parts markets, supplier selection is constrained by tight aviation regulations, and this is one reason why critical categories are often dominated by OEMs rather than by a broad competitive supplier base. For this reason, sourcing decisions in aerospace cannot be based on cost and availability alone, since suppliers and components must also satisfy strict regulatory, airworthiness, and qualification requirements. (Yen, 2009)

This regulatory logic is embedded directly in procurement practice. In the Cathay Pacific case, the procurement process had to ensure that "adequate airworthy spare parts were available at all times," while supplier performance was monitored through quantified measures such as lead-time variance, quality levels, and component performance. (Yen, 2009) Certification and quality assurance therefore operate not as peripheral checks, but as structural filters that shape supplier evaluation, monitoring, and continuation decisions across the aerospace supply chain. (Yen, 2009)

These requirements are reinforced by the need to preserve traceability and authenticity across the lifecycle of aerospace parts. The aviation sector has reported the detection of counterfeit aircraft parts in legitimate supply chains in both civil and military settings in the United States and Europe, showing that control over provenance is a central safety and quality issue rather than a secondary documentation task. In this context, certification is closely tied to traceability, because the legitimacy of a component depends not only on its technical function, but also on the verifiability of its origin, status, and compliance history. (Madhwal & Panfilov, 2017)

The regulatory burden is equally visible in outsourced MRO activities. FAA (Federal Aviation Administration) guidance, especially AC 120-106B, emphasizes that airworthiness agreements between certificate holders and maintenance providers must contain specific compliance requirements, while also reinforcing that certificate holders retain primary responsibility for airworthiness even when maintenance tasks are outsourced. Outsourcing therefore does not remove regulatory responsibility, but instead requires rigorous assessment, qualification, and authorization of external maintenance providers to ensure compliance with FAA standards. (Ison, 2026)

At the organizational level, these requirements also create an internal management challenge. MROs are described as needing a quality-driven, continuous improvement approach in which processes, programs, and systems are aligned with international standards to strengthen resilience, organizational reputation, and long-term sustainability. Integrated management systems also help address regulatory complexity by aligning requirements from multiple management systems, reducing overlap, and streamlining oversight while maintaining quality and satisfying regulatory requirements. Certification, regulation, and quality requirements therefore create not only external compliance obligations, but also substantial internal coordination and management demands within aerospace organizations. (Guinn et al., 2025)

2.2.3. Lead Times, Supplier Specialization, and Limited Substitutability

Lead times in aerospace are not merely operational inconveniences, but structural consequences of the industry’s product and process complexity. Aerospace products involve a large number of materials, design features, technical specialties, manufacturing processes, and assembly methods, and because of this complexity and the high degree of customization, aircraft production usually requires long lead times. (Horng, 2006)

This temporal challenge is closely connected to supplier specialization. The design and manufacture of reliable and economical aircraft require high expertise in numerous areas, which is why aircraft manufacturers depend heavily on external partners and subcontractors that have mastered “very specific technologies and processes.” (Richard Ivey School of Business Foundation, 2011) An average aircraft comprises around 55,000 parts, most of which are subcontracted, and these outsourced activities span major structural components, important subsystems, and maintenance-related services. (Richard Ivey School of Business Foundation, 2011)

Long lead times are amplified further by the geography of aerospace sourcing. In the Boeing case, suppliers were distributed across global locations, creating very long transport distances to the final assembly line in Everett. This made schedules vulnerable to weather disruptions, import difficulties, and transport problems. In such settings, time is not shaped only by production effort at the supplier level, but also by the complexity of moving large and technically sensitive components through international logistics networks. (Wendt, 2016)

Limited substitutability is the corresponding structural outcome of this specialization. One aircraft manufacturing case shows that delays in delivering finished aircraft doors were repeatedly caused by the unavailability of critical components, even though inventory buffers were maintained, because those critical parts were not easily replaceable within the production process. (Kumar et al., 2010) In MRO environments, the same logic appears in a different form: OEMs are generally preferred for new part models because of their expertise in maintenance and repairs, whereas PMA (Parts Manufacturer Approval) suppliers become viable mainly for older, non-critical models and may then offer shorter lead times. (Yen, 2009)

Lead times, supplier specialization, and limited substitutability are structurally intertwined in aerospace supply chains, because aircraft manufacturers depend on external partners that have mastered very specific technologies and processes. (Richard Ivey School of Business Foundation, 2011) Globally dispersed supply networks then make delays harder to absorb, as long transport distances and logistical uncertainty can disrupt schedules. (Wendt, 2016) In maintenance-related supply contexts, switching is further constrained because OEMs remain the preferred source for new part models, while alternative PMA suppliers are mainly viable for older, non-critical parts. (Yen, 2009)

2.2.4. OEM–Supplier Interdependence and Strategic Sourcing Relationships

OEM–supplier relationships in aerospace are not adequately explained by conventional buyer–seller logic. In complex aerospace programs, the strategic importance of the outsourced subsystem influences not only who supplies it, but also how the relationship is governed. Strategic sub-systems have a direct influence on the main attributes of the final product, require highly specialized design capabilities, and therefore create a much stronger degree of interdependence between customer and supplier than more standardized inputs do. In such settings, supplier relationships become part of the architecture of the product itself rather than a purely transactional procurement choice. (Mazaud, 2019)

This is why aerospace sourcing strategies differentiate between relationship types. In Airbus' case, the strategic degree of the subcontracted segment shapes the supplier policy, including the choice between single-source and multi-source arrangements. For less strategic segments, the traditional arm's-length approach gives priority to cost and preserves supplier flexibility through more standardized interfaces. For the most strategic segments, however, near-hierarchical partnerships are established, and cost is no longer treated as the decisive criterion on its own, but is evaluated through the broader notion of "total acquisition cost," which also includes quality, lead times, after-sales service, and procurement-related problems. (Mazaud, 2019) Aerospace sourcing is therefore strategic not only because suppliers matter, but because different categories of suppliers must be managed through fundamentally different coordination logics.

A related implication is that OEMs depend on suppliers not only for capacity, but also for competences they do not fully hold internally. Bombardier's case shows that aircraft manufacturers sought strategic partnerships in order to access external expertise and competences, while also using such partnerships to achieve economies of scale, focus on core competences, and reduce time-to-market in the development of new aircraft programs. Components provided by outside partners were at the same time expected to meet the highest standards set by regulators and to fulfill the manufacturer's promises to customers in terms of performance and operating costs. Strategic sourcing relationships in aerospace therefore combine capability dependence, performance dependence, and reputational dependence within the same inter-firm structure. (Richard Ivey School of Business Foundation, 2011)

At the same time, this interdependence creates a strategic dilemma. System integration on a risk-sharing basis can reduce OEM launch costs and shift financial burdens to external partners, but it also transfers technology, engineering know-how, and proprietary knowledge to those same partners. The same source warns that the long-range downside of such arrangements is that foreign risk-sharing partners may eventually become competitors, and it further describes this broader pattern as a preference for short-term financial gains at the expense of long-term strategic value. OEM–supplier interdependence in aerospace should therefore be understood as structurally double-edged: it enables access to specialized capabilities and financial risk sharing, yet it can also generate dependency, reduce strategic control, and weaken the long-term industrial position of the focal firm. (Pritchard & MacPherson, 2007)

2.2.5. Production-Oriented and Maintenance-Oriented Supply Flows in Aerospace

Aerospace supply chains do not end with aircraft production. They also extend into maintenance, repair, and overhaul activities, because the MRO industry is a critical component of the aviation landscape and ensures the safety and airworthiness of aircraft globally. Recent evidence further shows that MRO outsourcing covers multiple activities, including heavy maintenance, line maintenance, component repair, and spare parts management. (Ison, 2026)

Production-oriented flows follow a predominantly end-to-end logic. In the aircraft manufacturing literature, integrated supply chain management is described as an end to end (E2E) management mode linking front-end material production, manufacturing activity, and downstream delivery through cooperative relationships supported by capital, logistics, technology, and information flows. In structural terms, this means that manufacturing-oriented supply flows are primarily organized around the coordinated progression of materials, subassemblies, and work packages toward completion of the aircraft. (Lu & Liu, 2020)

Maintenance-oriented flows, by contrast, are directly linked to maintenance events rather than to a continuous production schedule. One aviation inventory study states that inventory management systems are very closely related to maintenance management systems, because “there is no use of materials unless maintenance is taking place.” (Al-Momani et al., 2020) In the same context, maintainers are responsible for pulling the exact parts required, checking constraints, and updating usage data, which then forms the basis for later analysis of consumption rates. (Al-Momani et al., 2020)

This difference becomes even clearer in demand behavior and repair management. At Cathay Pacific, future component demand was forecasted on the basis of projected fleet utilization and an individual component's life cycle, yet this still failed to capture demand arising from unscheduled removals, which accounted for nearly 79% of all removals. At the same time, repair management itself involved more than 80,000 repair orders per year, and repair shops had to be selected according to spare-part specialization, quality, price, and service level. Maintenance-oriented flows are therefore shaped not only by replenishment, but also by repair loops, service events, and uncertain technical findings. (Yen, 2009)

The distinction between both flow types is structurally important. Production-oriented flows are centered on an end-to-end progression of material production, manufacturing, and downstream delivery toward aircraft completion. (Lu & Liu, 2020) Maintenance-oriented flows, by contrast, are centered on sustaining airworthiness after the aircraft has entered service. (Ison, 2026) In parallel, maintenance-related inventory and material usage are organized around serviceability and actual maintenance activity rather than around a continuous production schedule. (Al-Momani et al., 2020)

2.3. Aircraft Manufacturing and MRO as Two Interconnected Aerospace Supply Domains

2.3.1. Aircraft Production Supply Chains

- **Purpose and role of aircraft production supply chains:**

Aircraft production supply chains are not simply procurement arrangements for individual parts, but structured industrial networks organized around subsystem integration and coordinated program execution. In this setting, the focal manufacturer retains the role of central coordinating actor, responsible for design, coordination, and control across the wider production network. In Airbus' case, the shift toward refocusing on core activities and engaging external suppliers transformed traditional subcontracting into a more cooperative network form, in which first-tier suppliers increasingly assumed intermediation functions. Airbus therefore operates as a systems integrator: it works with pivot firms to co-specify interfaces, define work packages, and ensure that strategically important subsystems can be integrated into the overall aircraft architecture. Aircraft production supply chains are thus a distinct aerospace supply domain because their primary role is to organize the coordinated realization of complex aircraft programs through controlled interaction between the OEM and specialized external partners. (Mazaud, 2019)

- **Production continuity and program stability:**

Within this production domain, the core objective is not aircraft uptime in service, but the stable execution of long-cycle, capital-intensive development and manufacturing programs. One extracted source describes civil aircraft manufacturing as an industry characterized by "high risks such as large investment, intensive capital and long cycle." (Lu & Liu, 2020) In such a context, production continuity depends on managing a complex industrial network in a structured way rather than only on the technical realization of the aircraft program. (Lu & Liu, 2020)

This makes schedule reliability a central concern. In aircraft development programs, delays at one point in the production architecture do not remain isolated: "In case if the delivery of a section is delayed, the entire delivery schedule is also delayed." (Daniela, 2021) A manufacturing case likewise identifies meeting delivery schedules as a major issue and shows that contractual penalties may be tied to deviations from the required delivery window. (Kumar et al., 2010) Aircraft production supply chains therefore prioritize continuity of assembly and coordinated program execution, because disruptions to a single work package can quickly affect the wider industrial schedule. (Daniela, 2021)

Program stability also depends on supplier capability, commitment, and visibility across the wider production network. In the A350 context, careful supplier selection required timely information exchange and assurance that suppliers had the necessary capacity and commitment to fulfil their tasks, while stronger supply chain visibility was seen as essential for taking corrective action quickly when interruptions arose. (Daniela, 2021) More broadly, one aerospace source states that comprehensive supply chain risk management is a significant part of ensuring the development and manufacturing process. In this sense, production continuity in aerospace is not simply a matter of keeping parts moving. It depends on maintaining a controlled and predictable program environment in which delays, coordination failures, and supplier shortfalls do not escalate into broader instability across the aircraft program. (Wendt, 2016)

- **Planned demand, industrial scheduling, and work-package coordination:**

Production supply chains are shaped by program planning rather than by unscheduled service events. In the A350XWB program, Airbus selected 58 direct suppliers to coordinate 128 design-and-build work packages, which were grouped into the categories of aero structures, systems, and cabins. This structure was intended to reduce development time and costs while enabling strategic suppliers to develop and produce different aircraft sections in parallel. (Daniela, 2021)

Industrial scheduling in this setting depends on early and coordinated supplier involvement. Airbus introduced a risk-sharing contract based on three main procurement principles: the allocation of comprehensive and integrated work packages, the early involvement of suppliers in the process, and closer collaboration with suppliers. With this supply policy, suppliers were given greater autonomy over component development, were involved 12–18 months earlier than before, and were selected from the concept phase to help define and develop new systems and components for the aircraft. (Daniela, 2021)

Production performance therefore depends not only on whether parts are delivered, but on whether work packages progress in a synchronized manner across the wider program structure. When suppliers are integrated early, given responsibility for defined packages, and coordinated through a shared development timetable, the production network is better positioned to support the timely realization of the aircraft program. (Daniela, 2021)

- **OEM control, system integration, and supplier coordination:**

Aircraft manufacturing is therefore not coordinated through a flat supplier market, but through an industrial architecture in which the OEM retains the role of system architect. One extracted source states that "a productive modular organization is orchestrated by an architect-firm," meaning that the focal manufacturer creates the network needed to realize the overall system. (Mazaud, 2019) In the same logic, the central coordinating actor in such a network is responsible for three simultaneous functions: design, coordination, and control. (Mazaud, 2019)

Within this structure, first-tier suppliers do not simply provide isolated parts. One extracted source describes them as carrying a broad range of responsibilities, including conception, production, and financing, while also organizing their own subcontracting activities. Supplier coordination is therefore layered rather than bilateral: Airbus coordinates its direct suppliers according to the strategic level of subcontracted sub-assemblies, and first-tier suppliers in turn must coordinate second-tier suppliers. (Mazaud, 2019)

Controlled interface management is central to making this arrangement work. In a modular perspective, interfaces are the "visible design rules" that define the place, function, and interaction modes of each module. (Mazaud, 2019) This allows complex aircraft programs to be distributed across specialized firms without abandoning overall system coherence. The closer a subcontracted element lies to the OEM's core competencies, the more coordination is based on supplier skills rather than on cost alone, which underlines that aircraft manufacturing depends on controlled integration as much as on outsourced production. (Mazaud, 2019)

- **Strategic sourcing, outsourcing, and risk-sharing in production networks:**

Strategic sourcing in aircraft production is not treated as a simple purchasing exercise, but as a way of combining internal core competences with external resources and knowledge. In Airbus' case, the systems integrator is defined as an "organization that builds up the network and controls it from an organizational and technological point of view," and it develops partnerships with the suppliers of the most strategic sub-assemblies in the form of strategic-type alliances. (Mazaud, 2019)

Outsourcing in this setting therefore serves a broader production logic than cost reduction alone. Since the mid-1970s, aircraft manufacturers have used offset programs not only to gain market access abroad, but also to reduce the level of self-funding needed to launch a new aircraft. Boeing later pushed this model further by outsourcing over 90% of the 787 program and relying on an international network of risk-sharing partners whose development costs were to be amortized across several aircraft programs. (Pritchard & MacPherson, 2007)

Risk-sharing arrangements can thus support program launch and distribute financial burdens across the production network, but they also create strategic exposure. One aerospace source notes that suppliers often need access to OEM knowledge and support in order to deliver their work packages at the required quality, which can expose the manufacturer to intellectual-property leakage and a gradual loss of unique selling points. (Wendt, 2016) Systems integration on a risk-sharing basis may also imply losses of skilled design, engineering, and R&D work in the home country. (Pritchard & MacPherson, 2007) Strategic sourcing and outsourcing in aircraft manufacturing should therefore be understood as selective and capability-driven arrangements that can strengthen program execution, but only if coordination and knowledge transfer remain tightly controlled.

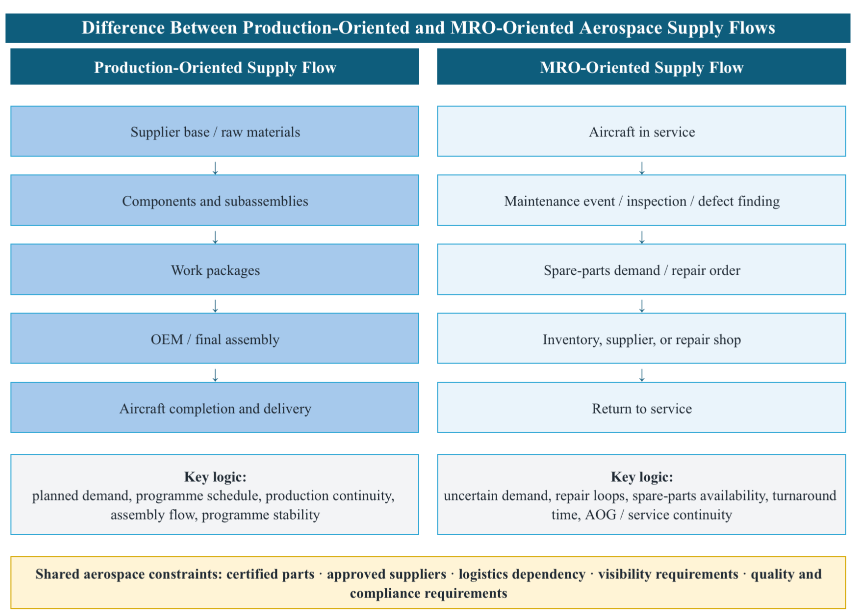
- **Why aircraft manufacturing forms a distinct aerospace supply domain:**

Aircraft manufacturing forms a distinct aerospace supply domain because it is organized through formal supplier roles, structured coordination logic, and program-based allocation of responsibilities rather than through service-event response. One aircraft-manufacturing source notes that large-aircraft suppliers can be classified from the dimensions of legitimacy, influence, urgency, and trust, which leads to differentiated categories such as key suppliers, adaptive vendors, collaborative vendors, and transactional suppliers. In the same vein, the sourcing logic of civil aircraft manufacturing has evolved to the point where risk sharing has become a mainstream mode of cooperation between major manufacturers and suppliers. (Lu & Liu, 2020)

This distinctiveness is reinforced by the fact that, in the A350 program, Airbus chose to outsource the design, development, and production of major subsystems to suppliers. Aircraft production supply chains should therefore be treated analytically as their own aerospace supply environment: their defining task is to realize a complex aircraft program through controlled supplier segmentation, coordinated industrial execution, and strategically distributed development responsibilities. (Daniela, 2021)

Figure 4

Difference Between Production-Oriented and MRO-Oriented Aerospace Supply Flows



Note. Source: Author’s own illustration.

2.3.2. MRO and Spare-Parts Supply Chains

- **Role and purpose of MRO and spare-parts supply chains:**

MRO and spare-parts supply chains begin where aircraft production ends: after the aircraft has entered service, their role is to support maintenance activity in a way that preserves operational readiness rather than program completion. One aviation inventory study states that an adaptive inventory system should reduce the chances of Aircraft on Ground (AOG) by ensuring the practical use of needed items based on maintenance requirements and by “maintaining the fleet, operational state, and high levels of serviceability and reliability at the least possible costs.” (Al-Momani et al., 2020)

This domain is also shaped by the fact that maintenance support is frequently organized through specialized external capabilities. Recent MRO research shows that airlines increasingly outsource maintenance in order to focus on core competencies such as flight operations and customer service, while gaining access to specialized skills, advanced technologies, and facilities that may not be available in-house. MRO and spare-parts supply chains should therefore be treated as a distinct aerospace supply domain whose primary purpose is to sustain serviceability, reliability, and continued aircraft operation through maintenance support after entry into service. (Ison, 2026)

- **Uncertain demand, maintenance events, and spare-parts availability:**

Unlike manufacturing demand, maintenance demand is not governed by a fixed program schedule, but by in-service maintenance requirements. At Cathay Pacific, future spare-parts requirements could be estimated from maintenance information, scheduled maintenance plans, and past usage patterns, yet the actual usage pattern remained highly unpredictable because of high demand variability. (Yen, 2009) Service inventory maintenance is therefore particularly challenging in aviation, since the needed spares are difficult to predict and inventory planning must still operate against minimum service-level requirements. (Al-Momani et al., 2020)

This uncertainty makes spare-parts availability more urgency-sensitive than production supply. Aviation inventory management is described as unique because it must balance maintenance demand and ordering decisions while keeping costs as low as practical without compromising the readiness necessary to complete the mission. Where required components are unavailable, consequences can be severe: an AOG item is one that prevents the aircraft from being released to service, and AOG-basis spares may need to be delivered within 24 hours and at roughly three times the normal cost. MRO and spare-parts supply chains are therefore shaped not only by replenishment efficiency, but by the need to respond rapidly to maintenance-driven part requirements that can interrupt aircraft operation. (Al-Momani et al., 2020)

- **Repair cycles and turnaround time:**

Repair cycles make MRO supply logic fundamentally different from simple replenishment. Some aircraft parts are economically repairable and are repeatedly restored to a fully serviceable condition during operation, which means spare-parts supply must be linked to inspection, repair, overhaul, and return-to-service processes rather than only to one-way replacement flows. At Cathay Pacific, this translated into more than 80,000 repair orders per year, and repair shops had to be selected not only for price, but also for the capability and capacity to repair the full range of installed components as well as for their service level. (Yen, 2009)

Turnaround time then becomes a central supply variable. As one Cathay Pacific manager put it, aviation spare-parts management is shaped by “the turnaround time, lead time, repair time,” and the logistics function therefore aimed to minimize the duration and number of processes required to move parts between warehouse, aircraft, and repair centres. (Yen, 2009) Inventory reduction depended not only on supplier lead time but also on turnaround time from repair shops, while shortage situations could trigger same-day express AOG shipments, pool loans, or inter-airline borrowing to avoid longer downtime. MRO supply performance is therefore shaped by the speed and reliability of repair loops as much as by replenishment itself. (Yen, 2009)

- **MRO companies, outsourcing structures, and maintenance hubs:**

MRO and spare-parts supply chains are also defined by a distinctive organizational structure. Because aircraft remain in service for decades, maintenance, repair, and overhaul are required throughout their operational life, and the relevant customers include aircraft owners and operators seeking to comply with safety requirements while controlling maintenance costs. (Liangrokapart & Sittiwatethanasiri, 2022) In this environment, maintenance support is not organized only within airlines themselves, but increasingly through specialized external providers and differentiated make-or-buy arrangements. (Ison, 2026)

One extracted source notes that the decision to outsource aircraft maintenance is complex and depends on factors such as cost, quality, safety, and regulatory compliance, while the make/buy model is commonly used to compare in-house provision with external sourcing in terms of labor costs, facility overhead, access to specialized skills and technology, and operational efficiency. Provider selection then becomes part of the supply structure itself, since technical expertise, capacity, turnaround time, and quality-related criteria shape which MRO organizations can support a given fleet. (Ison, 2026)

The organizational geography of this domain is equally important. For MRO operations, the optimal placement of maintenance stations and spare-parts depots at key nodes of the network is a central issue, because a significant part of maintenance activity depends on ferrying spare parts through the airline network. (Tsakalerou et al., 2022) At the same time, the rise of new MRO hubs in Asia and the Middle East shows that maintenance support is increasingly organized through regional service concentrations rather than only through local in-house capability. (Ison, 2026) MRO and spare-parts supply chains should therefore be understood as a structured support environment built around specialized providers, outsourced maintenance relationships, and hub-based network positioning that together determine how maintenance support and spare-parts flow are organized after aircraft entry into service.

- **Why MRO and spare-parts supply form a distinct but connected aerospace supply domain:**

MRO and spare-parts supply form a distinct aerospace supply domain because, as one extracted source states, they involve "complex networked supply chains for aircraft's spare part purchase and delivery for aircraft's maintenance and repair," in which parts are shipped to assembly hubs globally and carry specific life expectancy, requirements, and maintenance attributes. (Madhwal & Panfilov, 2017) Yet this domain remains closely connected to the wider aerospace supply chain, because aircraft do not leave the supply network once production is complete; rather, they continue to depend on specialized parts, logistics flows, and maintenance support throughout their operational life. (Madhwal & Panfilov, 2017)

For this dissertation, that distinction is analytically important. MRO is oriented toward prolonging the aircraft life cycle and supporting operators that must comply with safety requirements while controlling maintenance costs, rather than toward the execution of a new-aircraft program. (Liangrokapart & Sittiwatethanasiri, 2022) Its close connection to the wider aerospace supply chain becomes especially visible in spare-parts sourcing, because MRO organizations traditionally depend on OEMs for critical parts and supplies, while insufficient material and part availability can slow or halt maintenance work and adversely affect both revenue and business reputation. (Guinn et al., 2025) At the same time, aircraft spare-parts support itself takes the form of a complex networked supply chain in which parts are purchased and delivered for maintenance and repair, shipped through globally located hubs, and managed according to their life expectancy and maintenance attributes. MRO and spare-parts supply should therefore be treated as a distinct but connected aerospace supply domain: distinct because its immediate objective is continued serviceability after aircraft entry into service, but connected because it remains structurally tied to the wider aerospace supplier, logistics, and support network. (Madhwal & Panfilov, 2017)

2.4. Supply Chain Disruptions and Vulnerabilities in Aerospace

2.4.1. Pandemic-Related Disruptions and Post-COVID-19 Effects

During the COVID-19 outbreak, customer demand became uncertain, while shortages on supply markets, loss of key suppliers, supplier temporary closure, transportation risks, and single sourcing emerged as major disruption-related risks. (Ghadir et al., 2022) For aviation, the pandemic exposed structural fragility across the supply chain by disrupting aircraft manufacturing, airport operations, and airline logistics at the same time. It also grounded fleets, closed airports, constrained aviation-fuel availability, and severely disrupted aircraft-parts flows, which forced airlines, MRO organizations, OEMs, and regulators to reconsider procurement, maintenance-planning practices, and the design of aircraft-parts networks. (Syed, 2025)

The significance of the pandemic, however, did not end with the initial shock. In the post-COVID-19 phase, the crisis accelerated a broader restructuring of aviation supply chains, as resilience increasingly became a design objective rather than a temporary emergency response. During this restructuring period, tools such as AI-based demand forecasting, IoT-supported aircraft and cargo monitoring, digital-twin simulation, and blockchain-based traceability moved closer to mainstream operational practice. In this context, the post-pandemic period can be understood not simply as a recovery phase, but as a transition toward more adaptive and technology-supported supply-chain configurations. (Syed, 2025)

For aircraft manufacturers, this shift was closely connected to the need for stronger visibility, improved coordination, and more stable planning across fragmented supplier networks. The post-pandemic restructuring therefore favored not only technology adoption, but also tighter collaboration and more adaptive resilience models across the aviation ecosystem. Rather than relying exclusively on pre-crisis cost-oriented structures, firms increasingly moved toward arrangements intended to improve anticipation, responsiveness, and continuity under future disruption. (Syed, 2025)

For MRO organizations, the post-pandemic effects were especially severe because shortages in material and part availability could directly slow or halt maintenance activity. This meant that disruption was not limited to procurement inefficiencies, but translated into operational delay, revenue loss, and reputational risk for maintenance providers. The situation was further aggravated by the structural dependence of many MROs on OEM supply, since OEMs often prioritize new-aircraft production over aftermarket support, thereby increasing the exposure of maintenance providers to shortages, delays, and cost escalation in times of disruption. In that sense, the pandemic did not only expose the vulnerability of aviation supply chains in general, but also highlighted that manufacturing and MRO were affected through different mechanisms and with different operational consequences. (Guinn et al., 2025)

2.4.2. Geopolitical Conflict, Sanctions, and Trade-Related Exposure

Geopolitical conflict and sanctions exposed aerospace supply chains not merely to isolated transport problems, but to structural interruptions in the flow of goods, services, technologies, and market access. In highly interdependent global networks, sanctions can abruptly sever supplier relationships, block critical components, and force firms to intensify supplier and customer vetting in order to avoid dealings with blacklisted actors. This means that trade-related exposure is not limited to the sanctioned country itself. Rather, it spreads through connected networks and compels firms to reconfigure sourcing, transport, inventory, and even broader business models under severe time pressure. (Rafikova, 2025)

In aviation, these effects became especially visible after the escalation of the war in Ukraine in 2022. Sanctions and countermeasures targeted aircraft, parts, equipment, insurance, maintenance services, airspace access, ports, and road transport, thereby affecting both the physical and regulatory conditions under which aerospace supply chains operate. As a result, traditional Europe-Asia transport corridors became less accessible, cargo had to be rerouted, and longer journeys, higher fuel consumption, increased personnel costs, and reduced transport capacity raised the cost of continuity for airlines and logistics providers. (Cekerevac

& Bogavac, 2023) More broadly, the sanctions shock showed that corridor dependence is itself a structural supply-chain exposure. When established air, sea, or land routes become politically constrained, firms are forced to reconfigure carriers, routes, and sourcing channels under severe time pressure. (Rafikova, 2025)

The aerospace sector is particularly vulnerable because geopolitical conflict also affects access to strategic materials. The Russia-Ukraine war highlighted the industry's dependence on a limited number of suppliers for inputs such as neon, titanium, and palladium, all of which are essential for aerospace manufacturing and related technologies. Ukraine had supplied approximately 50 percent of the world's neon before the earlier Crimea-related disruption in 2014, while Russia remained a major actor in titanium and palladium supply, creating pronounced geopolitical dependencies. When conflict, sanctions, or export restrictions affect such concentrated supply bases, the result is not only shortage risk, but also price escalation and broader instability across the aerospace production system. In this sense, geopolitical conflict and sanctions revealed that aerospace vulnerability is rooted not only in global dispersion, but also in the political fragility of trade routes, supplier relationships, and critical-material dependencies. (Magness, 2024)

2.4.3. Raw-Material Shortages and Capacity Bottlenecks

Raw-material shortages exposed a deeper layer of aerospace vulnerability because they affected inputs that are not easily substitutable and that are embedded in safety-critical and performance-critical technologies. In aerospace, neon is essential for semiconductor chips used in navigation and flight control systems, while titanium and aluminum alloys are indispensable for airframes, engines, landing gear, and fastening elements. Palladium is likewise required in aerospace applications because of its corrosion resistance, electrical conductivity, thermal-management properties, and catalytic performance. When disruption affects such materials, the consequences are not confined to procurement cost, but extend to the technical basis of aircraft production itself. (Magness, 2024)

These shortages also showed how quickly material scarcity can develop into capacity bottlenecks. The forced shutdown of major Ukrainian neon producers and the disruption of titanium-processing inputs reduced availability in upstream material chains, while aerospace manufacturers remained dependent on specialized suppliers and processors. (Magness, 2024) At the program level, this means that firms must not only select suppliers carefully, but also ensure that they have the necessary capacity and commitment to fulfil their tasks, since a delay in one section delays the entire delivery schedule. Raw-material shortages therefore create more than price pressure: they constrain qualified supply capacity, weaken schedule stability, and increase the risk that a localized shortage develops into a broader production bottleneck. (Daniela, 2021)

2.4.4. Logistics Disruptions and Transportation Constraints

Logistics disruptions revealed that aerospace vulnerability is not located only in suppliers and materials, but also in the transport nodes and corridors that connect global production and maintenance systems. During the COVID-19 period, lockdown measures disrupted world trade on a large scale, and the closure of the port of Shanghai, which handles a substantial share of Chinese exports, redirected cargo to other ports and created major supply difficulties. The pandemic also caused major disruption in the flow of electronic components, raw materials, and parts originating from China, showing how strongly aerospace continuity depends on the stable functioning of global transport infrastructure. (Cekerevac & Bogavac, 2023)

These transportation constraints also demonstrated that logistics disruption is not simply a question of delay, but of adaptation capacity. As supply routes, ports, and cargo flows became unstable, firms were forced to reconsider both source selection and the coordination of changes from one source or transport method to another. In such an environment, adaptability became a central requirement, while access to real-time supply-chain and cargo-location data gained strategic importance because it improved visibility over operations and expected delivery times under disrupted conditions. (Cekerevac & Bogavac, 2023)

2.4.5. Vulnerabilities of Lean, Globally Dispersed, and Concentrated Sourcing Models

Efficiency-oriented and geographically dispersed sourcing models create important advantages, including lower costs, access to specialized capabilities, economies of scale, and benefits from geographic location diversity. At the same time, however, these same structures introduce more complexity and risk, because modern supply chains span multiple countries and multiple supplier tiers that are not fully visible to downstream firms. Where suppliers further subcontract work, many firms have little or no visibility into Tier 2 or Tier 3 levels, which increases the likelihood that disruption in distant upstream nodes will come as an operational surprise rather than as a manageable risk. In that sense, the vulnerability of globally dispersed models lies not only in long transport distances, but also in limited transparency across the extended network. (Shih, 2018)

Concentrated sourcing structures create a related but distinct form of fragility. Globalization has increasingly led multiple competitors to rely on the same upstream suppliers, while many downstream firms have only limited visibility into those higher-tier sources until disruption occurs. Although such concentration can reduce cost through volume aggregation and economies of scale, it also means that a single supplier shock can affect several firms at the same time. (Shih, 2018) In aviation-related contexts, this fragility is intensified by regulation and qualification constraints, since some parts remain dominated by OEM supply and the resulting high supplier concentration limits negotiation power and reduces switching flexibility. (Yen, 2009) Lean and cost-oriented sourcing models therefore become especially vulnerable when they combine low slack, limited visibility, and high supplier concentration within the same network.

2.4.6. Comparative Disruption Effects on Manufacturing and MRO Operations

Manufacturing and MRO were exposed to the same disruption environment, but the operational consequences were not identical. In aircraft manufacturing, disruption primarily threatens the coordination and integration of complex subsystems across an extended industrial architecture. One aerospace source describes the key first-tier actor as a "strategic partner which, on the one hand, co-designs the sub-system under its responsibility with the Integrator, co-specifying the required interfaces," which underlines how strongly manufacturing continuity depends on synchronized design, coordination, and system integration between the OEM and major suppliers. (Mazaud, 2019) In such a setting, disruption is especially damaging because it interferes with the orderly integration of subassemblies rather than only interrupting the physical arrival of parts. (Mazaud, 2019)

For MRO operations, by contrast, disruption effects emerge more directly in network execution, maintenance planning, and cost exposure. One extracted passage states that "the pandemic-related severe restriction of flights worldwide has created a problem of historic proportions for Aircraft Maintenance 4.0," because altered routes rendered much historical data obsolete. (Tsakalerou et al., 2022) The same source notes that the impact of unplanned maintenance events is felt directly through "increased labor costs and inventory expenses," while also affecting wider network operations. (Tsakalerou et al., 2022) In addition, maintenance costs are "not amenable to cost reductions equivalent to the reduction of flight operations because maintenance hubs are not easily movable and incur hefty, fixed costs," which means that MRO providers remain financially and operationally exposed even when traffic falls. (Tsakalerou et al., 2022)

A further distinction is that MRO disruption effects extend into operational assurance itself. Fresh extracted evidence identifies labor shortages, supply chain disruptions, and cyber incidents as core operational risks in MRO. At the same time, human factor–related errors, referred to by the Federal Aviation Administration as the "Dirty Dozen," account for nearly

80% of maintenance mistakes, while only 9% of MROs implement security standards and fewer than half conduct regular cybersecurity assessments. (Guinn et al., 2025) Taken together, this indicates that manufacturing disruptions primarily endanger subsystem integration and coordinated program execution, whereas MRO disruptions more directly affect maintenance performance, network responsiveness, fixed-cost exposure, and the preservation of airworthiness under unstable conditions. (Guinn et al., 2025)

2.5. Supplier Risk in Aerospace: Manufacturing and MRO Perspectives

2.5.1. Concept and Relevance of Supplier Risk in Aerospace

Supplier risk in aerospace should not be treated as a narrow delivery problem alone. In this industry, supply chain management already covers a broad set of dimensions, including "technical specifications, concurrent engineering, strategic engineering alliances, quality control, product co-development, certification of suppliers, delivery time, risk-sharing, cost-sharing, production volumes and prices." (Niosi & Zhegu, 2005) This breadth shows that supplier-related exposure in aerospace can arise through several interconnected performance dimensions rather than through schedule adherence alone.

This risk is especially relevant in aircraft manufacturing because large aerospace programs rely on extensive outsourcing and risk-sharing structures. In the A350 context, Airbus planned to outsource more than 50% of the airframe work and expected selected risk-sharing partners to absorb around $2.5 billion of development costs. Such arrangements may support program launch, market access, and financial burden-sharing, but they also make program continuity more dependent on external partner capability, financial robustness, and strategic alignment. Supplier risk in manufacturing is therefore directly connected to the stability of development programs, the execution of outsourced work packages, and the broader strategic consequences of externally distributed production architectures. (Pritchard & MacPherson, 2007)

In MRO-related environments, supplier risk becomes especially relevant because support systems operate across very long life cycles and are exposed to inventory problems such as surplus and unused spares, expired items, unmet requirements caused by budget shortages, and warranty periods that expire because items are not monitored closely. (Al-Momani et al., 2020) The financial burden of this support is also significant, since the carrying costs for aviation spare-parts inventory are relatively expensive. (Yen, 2009) In addition, vendor performance in such settings must be assessed through criteria including lead time, priority in dealing with urgent issues, the handling of warranty claims, responses to supply deficiency reports, and the treatment of returned items. (Al-Momani et al., 2020)

2.5.2. Operational and Quality-Related Supplier Risks

Operational and quality-related supplier risks in aerospace manufacturing arise not only from physical defects in supplied components, but also from weaknesses in communication and integration across the supplier network. One comparative study of Boeing and Airbus supply practices states that ineffective communication with suppliers and poor supply chain integration can result in serious quality issues, while changing order volumes can become stronger at earlier supplier stages and, as a result, lead to more errors later in the supply chain. The same source also identifies supply chain integration as a means of achieving an acceptable level of quality along the supply chain and of supporting better product design. This indicates that operational and quality risk in aerospace manufacturing is closely linked to coordination quality across multiple tiers rather than to isolated supplier performance alone. (Horng, 2006)

The supplier-selection process therefore becomes part of operational and quality risk control. In the A380 and 787 programs, first-tier suppliers were brought into workshops, participated in the specification phase, and were subsequently evaluated according to their suitability and capabilities as suppliers, vendors, or institutional partners. In aerospace manufacturing, ineffective communication with suppliers and poor supply chain integration can result in serious quality issues, while changing order volumes can become stronger at earlier supplier stages and, as a result, lead to more errors later in the supply chain. At the same time, supply chain integration is associated with several benefits, including the achievement of an acceptable level of quality along the supply chain and better product design. (Horng, 2006)

2.5.3. Financial and Capacity-Related Supplier Risks

Financial and capacity-related supplier risks in aerospace manufacturing are closely connected. Evidence from aircraft-component production shows that numerical control (NC) machining capacity, together with broaching and grinding capacity, became a major bottleneck, and that some components had to be transferred to subcontractors because existing capacity was inadequate for the increased production rate. A managerial account from the same case notes: “Initially, I was doing 100% of the production in-house. But I started outsourcing to meet capacity requirements and increase cost efficiency. It took more than 15 to 20 years to develop the sub-contractors because we need to ensure quality and train them to interpret designs.” (Kumar et al., 2010) The financial consequences can also be severe, since non-delivery of aircraft doors can result in penalty costs that wipe out the profit earned from each unit sold. (Kumar et al., 2010)

In MRO-related environments, the financial dimension of supplier risk is intensified by the capital intensity of spare-parts support. One aviation case reports that only 30% of inventory in a traditional airline was active, while another 30% was slow-moving but necessary and 40% was dead stock. The same source estimates that the airline industry spent over US$10 billion per year on spare parts, that the value of spare engines for major airlines exceeded US$11 billion, and that the overall value of spare parts stored by the airline industry increased from US$45 billion in 1995 to US$50 billion in 2002, of which 80% was owned by airline operators. This indicates that financial supplier risk in MRO is not limited to the purchase price of parts, but also includes the capital tied up in inventory that is costly to hold and difficult to turn over. (Yen, 2009)

2.5.4. Regulatory, Certification, and Compliance-Related Supplier Risks

In aerospace manufacturing, supplier risk is shaped not only by production capability, but also by the ability to satisfy formal technical, quality, contractual, and confidentiality requirements. Airbus-related evidence shows that the supplier-selection process begins with the signature of a Non-Disclosure Agreement (NDA), followed by Requests for Information (RFI) or Requests for Technical Information (RFTI), the creation of a shortlist, and the issue of formal Requests for Proposal (RFP). Supplier responses are then evaluated against specific criteria based on Airbus's technical, quality, contractual, and commercial requirements. This indicates that supplier risk in manufacturing is closely linked to compliance with formal qualification and selection procedures before a supplier is accepted into the program. (Mazaud, 2019)

The compliance burden is also visible at the level of supplied materials and technologies. In the Airbus supply chain, suppliers of composite materials are coordinated not only according to cost but also according to material quality, and a specific qualification is imposed on them. By contrast, raw-material suppliers are managed almost exclusively on a cost criterion only once the required quality standards have been met. This suggests that regulatory and compliance-related supplier risk becomes especially pronounced where the supplied input is technologically sensitive and must satisfy stricter qualification conditions before it can be integrated into the wider production system. (Mazaud, 2019)

In MRO-related environments, certification and compliance requirements create a different but equally important form of supplier risk. One aviation case notes that all suppliers of aeroplane spare parts were required to possess special legal certifications and formal protocols, including stipulations concerning the assumption of responsibility in case of an accident. The same source states that mechanics certified by the FAA were required to check all non-deferrable repairs before departure and verify that all regulations were met, while the FAA could ground an aircraft if deferrable repairs were not completed within the stipulated timeframe. In this context, supplier risk is not limited to part availability alone, but also depends on whether suppliers and repair-related actors meet the formal compliance conditions required to keep aircraft airworthy and in service. (Yen, 2009)

A further compliance-related challenge in MRO arises from the characteristics of the parts themselves. Aircraft components may consist of dozens or hundreds of parts, can remain in use for more than two decades, and may be repaired or overhauled many times. According to the same source, these conditions, together with aviation-authority requirements such as certification and traceability and broader issues of reliability and safety, increase the cost of obtaining and keeping aviation spare parts. Regulatory and certification-related supplier risk in MRO therefore extends beyond approval at the point of purchase and continues across the full life cycle of spare parts and repair activities. (Yen, 2009)

2.5.5. Geopolitical, Market, and Location-Related Supplier Risks

In aerospace manufacturing, geopolitical, market, and location-related supplier risks arise because sourcing and industrial cooperation are often tied not only to cost and capability, but also to market access, host-country requirements, and the geographic distribution of production. Airbus-related evidence shows that research and the penetration of new markets became fundamental, and that production units were established in China, India, and Brazil according to the requirements of local authorities; this created both cost advantages and the risk that local players could capture Airbus know-how. (Mazaud, 2019) A related source states that government-supported risk-sharing partners in the East may require Western suppliers to participate in host-country production through outsourcing or offshoring, local design offices, and possibly the licensing of production, while Airbus informed first-tier suppliers that outsourcing to Asia was a requirement and that non-compliance would entail significant penalties. (Pritchard & MacPherson, 2007) This indicates that geopolitical and location-related supplier risk in manufacturing is closely linked to foreign-location commitments associated with market access and industrial participation.

Airbus's supply rationalization strategy included an extension of calls for tenders to foreign competition. (Mazaud, 2019) In addition, one MRO-oriented source notes that competition has become more global and that new major players have entered the supplier market. In MRO-related environments, the location dimension appears in a different form. The same source states that local supply chains often have lower technological capacities and therefore require strong government support to reduce the technological gap; it also recommends that local supply chains form a cluster to strengthen technological capacity. (Liangrokapart & Sittiwatethanasiri, 2022) This indicates that location-related supplier risk in MRO is closely linked to the regional availability of capable support ecosystems.

2.5.6. Logistics, Transportation, and Lead-Time-Related Supplier Risks

In aerospace manufacturing, logistics and lead-time-related supplier risks are closely tied to schedule reliability. One manufacturing case shows that the assembly of aircraft doors is labor intensive and involves long procurement lead times for parts, while manufacturing cycle times are affected by uncertainty in the availability of manpower, parts, and machines. In such an environment, delays in delivery can generate substantial losses, which is why suppliers are expected to adhere to strict delivery schedules. (Kumar et al., 2010)

In MRO-related environments, the same risk category appears more directly in the movement of spare parts and in the coordination of repair support. One aviation case defines logistics management as the effort to minimize the duration and number of processes required to transport spare parts from one place to another, including the shipment of ordered inventory from the warehouse to the aircraft and to and from repair centers. The same source notes that, in order to reduce lead times, parts were usually shipped individually between repair houses and major hubs, whereas parts that were less sensitive to lead time were consolidated in order to reduce costs. In Australia, for example, a fixed import tax was charged on every shipment, so decisions had to balance the time advantage of immediate movement against the cost advantage of waiting and consolidating several parts into one shipment. This shows that logistics and lead-time-related supplier risk in MRO is not only a question of transport delay itself, but also of how organizations manage the trade-off between speed, service continuity, and logistics cost under operational pressure. (Yen, 2009)

2.5.7. Information, Visibility, and Coordination-Related Supplier Risks

In aerospace manufacturing, information and coordination-related supplier risks arise where visibility across the network is weak and coordination between participating firms is insufficient. One aerospace source identifies lack of information visibility and failure of coordination across the supplier network as the main reasons contributing to the bullwhip effect. The same source states that the bullwhip effect increases costs because of the basic misalignment between supply and demand, inventory hedging and duplication, shipping delays, and poor delivery times. (Horng, 2006) In addition, Airbus-related evidence indicates that increasing the outsourcing of components created issues in coordination and communication during the aircraft development process, which led Airbus to introduce a partnership model intended to facilitate closer coordination and cooperation with suppliers. (Daniela, 2021)

In MRO-related environments, the same risk appears through the complexity and limited controllability of aircraft-parts networks. One source on aircraft-parts supply chains states that these chains involve very large flows of information, products, and money. Where supply chain visibility is limited, organizational control over supplier activities becomes weaker, increasing vulnerability to risks such as the entry of counterfeit parts into the network. Information, visibility, and coordination-related supplier risk in MRO therefore concerns not only delayed or incomplete data exchange, but also reduced traceability and weaker control across globally dispersed spare-parts and maintenance flows. (Madhwal & Panfilov, 2017)

2.5.8. Spare-Parts, Repair-Network, and Service Continuity Risks in MRO

In MRO-related environments, service continuity depends on more than the procurement of spare parts alone. One Maintenance 4.0 source explains that the basic aircraft-maintenance problem involves routing individual aircraft across the network so that each one reaches a maintenance station within prescribed manufacturer recommendations, aviation-authority regulations, and internal airline guidelines. The same source notes that this problem is complicated not only by day-to-day disruptions such as flight delays, but also by workflow capabilities and available inventory at each maintenance station. In addition, the production of aviation spare parts is characterized by technologically demanding, low-volume manufacturing and by the need to supply many different item types with tailored technical requirements. This makes spare-parts dependency in MRO especially acute, because continuity of maintenance support depends simultaneously on where inventory is positioned, whether the required station can support the work, and how quickly specialized items can be obtained. (Tsakalerou et al., 2022)

Repair-network dependency adds a further layer of risk. The same source from Kazakhstan states that major maintenance includes heavy airframe and engine work and notes that Air Astana engages third-party maintenance and repair organizations in Asia and Europe, including Hong Kong, Istanbul, and Frankfurt. It also reports that spare parts are held as inventory to maintain redundancies for uncertain demand in terms of both location and time. (Tsakalerou et al., 2022) Recent data suggests that external MRO provision remains a substantial part of airline maintenance support. Worldwide airline MRO expenditure amounted to roughly US$93.9 billion in 2023, and U.S. airlines were already assigning 47% of their maintenance spending to outsourced providers in 2016, representing US$7.3 billion. The source also indicates that airlines are increasingly relying on specialized external firms for component repair and spare-parts inventory management in order to improve cost control, raise operational efficiency, and make use of provider-specific expertise. (Ison, 2026) Taken together, these findings indicate that spare-parts, repair-network, and service continuity risks in MRO arise from a structurally dependent support model in which maintenance performance relies on external providers, distributed repair locations, and the availability of the right spare part at the right place and time.

2.5.9. Manufacturing versus MRO Risk Consequences

Aircraft manufacturing tends to convert supplier risk primarily into development and coordination problems rather than into immediate service interruptions. One aerospace case indicates that the design and production of reliable and cost-efficient aircraft requires expertise across many highly specialized fields, which is why manufacturers depend on external partners and subcontractors with specific technological capabilities. (Richard Ivey School of Business Foundation, 2011) Airbus-related evidence likewise shows that the broader outsourcing of components created coordination and communication difficulties during the aircraft-development process, which led the company to reorganize cooperation with suppliers through an “Extended Enterprise” partnership approach. (Daniela, 2021) In this environment, supplier-related problems are especially consequential when they disrupt the coordinated progress of development work across the wider production system, since manufacturing performance depends on effective collaboration among multiple specialized contributors.

By contrast, in MRO environments supplier risk is translated more directly into aircraft availability and service performance. One aviation case makes clear that repair turnaround is a critical issue because maintenance delays generate both direct and indirect costs: beyond standard passenger-compensation expenses, keeping an aircraft on the ground was estimated at US$60 per minute, while prolonged disruption could also undermine customer satisfaction and even lead passengers to choose competing airlines. In this setting, supplier-related problems are therefore especially consequential when they delay the return of aircraft to service, since the effects appear quickly in operational continuity, commercial reliability, and cost exposure rather than primarily in long-cycle program coordination. (Yen, 2009)

2.6. Supplier Risk Assessment Approaches

2.6.1. Purpose and Role of Supplier Risk Assessment in Aerospace

The identification of supplier risk categories does not yet provide a sufficient basis for aerospace decision-making. Once operational, financial, regulatory, logistics, information, and service-continuity risks have been recognized, firms still need to determine which exposures deserve the greatest managerial attention, which suppliers require closer control, and which response is most appropriate. Supplier risk assessment therefore performs a bridging function between risk awareness and managerial action. In the wider supply chain risk literature, this process is understood as one of "identifying, assessing, mitigating, and monitoring potential disruptions in the supply chain," which means that its role is not simply descriptive, but decisively evaluative and action-oriented. (Ghadir et al., 2022)

This role becomes especially important in aerospace because supplier-related exposure cannot be managed uniformly. Resource limitations make it unrealistic to respond to all identified risks with the same intensity, so assessment is needed to establish priorities and differentiate between more and less consequential exposures. (Ghadir et al., 2022) In aerospace procurement, this prioritization function is closely linked to sourcing strategy. Airbus-related evidence shows that Strategic Purchasing Orientation is intended to provide "pragmatic advice on how to manage the extent of its own supply of weakness and treat it with a comprehensive strategy to manage supply," while the underlying purchasing matrix proceeds from classification and market analysis to strategic positioning and action planning for outsourced items. (Mazaud, 2019) Supplier risk assessment thus serves not only to identify vulnerability, but also to structure decision-making about how suppliers and purchased items should be managed.

In practical aerospace settings, supplier risk assessment also fulfills an operational control function. In the Cathay Pacific spare-parts context, suppliers were monitored through quantifiable indicators that assessed both part quality and supplier performance, including average and variance of lead time, quality levels, and component performance. This indicates that assessment is not limited to the initial choice of supplier, but extends into ongoing performance surveillance after the supplier has already become part of the network. (Yen, 2009) A similar logic appears in military aviation, where the proposed inventory management system was designed not only to track inventory and generate reorder decisions, but also to identify deficiencies linked to materials, design, vendor, or storage conditions and to monitor warranty-related issues before they created avoidable losses. (Al-Momani et al., 2020) In this sense, supplier risk assessment becomes part of a continuous diagnostic capability rather than a one-time procurement exercise.

2.6.2. FMEA-Based Approaches and their Adaptation to Supply Risk

Failure Mode and Effects Analysis (FMEA)-based logic represents one of the clearest structured approaches found in the supplier-risk literature. As one source states, "FMEA is a valid risk assessment technique" and is used as a "structured and proactive risk management method to identify potential risks and estimate their impacts and relevance in various industries." (Ghadir et al., 2022) In that sense, its value lies not only in identifying possible disruptions, but also in translating them into an ordered assessment logic that supports managerial prioritization. A central feature of the method is that "the risk priority number (RPN) for each failure mode is calculated by multiplying the scores of risk factors like occurrence (O), severity (S), and detection (D)." (Ghadir et al., 2022)

For supply-chain applications, however, the literature does not leave FMEA in its basic form. The same study applies a modified version in which "BWM has been applied to calculate risks' weight," and it justifies this choice by noting that BWM is a "vector-based MADM method," that is, a Multi-Attribute Decision Making approach requiring fewer comparisons than pairwise comparison matrix-based methods such as AHP (Analytic Hierarchy Process). (Ghadir et al., 2022) This is important because supplier-related disruptions do not emerge as one single type of failure, but across several categories, including demand, supply, logistics, political, manufacturing, financial, and information risks. (Ghadir et al., 2022) FMEA therefore becomes more useful when it is adapted to weighted prioritization rather than used only as a descriptive list of possible failures.

This adaptive tendency is also visible more broadly in the supply chain risk management (SCRM) literature. The extracted material shows that supply chain risk management studies frequently combine FMEA with other methods such as simulation, fuzzy logic, and MADM techniques, which suggests that FMEA is often used as a structured starting point rather than as a sufficient stand-alone model. For aerospace, this makes FMEA-based logic relevant above all as an initial assessment route, but the extracted evidence points more toward an adaptable foundation than toward a fully aerospace-specific model. (Ghadir et al., 2022)

2.6.3. Multi-Criteria Supplier Evaluation Models

Multi-criteria supplier evaluation models seek to compare suppliers by weighting several attributes simultaneously instead of relying on one criterion alone. In the MRO-related literature, “The AHP method is a multicriteria decision-making technique” that “performs pairwise comparisons to develop the relative importance of attributes at each level of the hierarchy and assess alternatives.” (Liangrokapart & Sittiwatethanasiri, 2022) The same source also notes that conventional SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis “has no analytical aspect to quantify the importance of each SWOT attribute or the selection of alternatives,” which is why it was converted into a hierarchy and combined with AHP so that “the SWOT group and their attributes are prioritized systematically.” (Liangrokapart & Sittiwatethanasiri, 2022) This shows the central contribution of multi-criteria models: they turn broad qualitative judgments into an ordered comparison of factors and alternatives. (Liangrokapart & Sittiwatethanasiri, 2022)

At the same time, the aerospace material suggests that such models are most useful as part of a broader selection process rather than as a complete decision rule on their own. One manufacturing source states that “different supplier selection methods are adopted” according to different products, including open bidding procurement, limited competitive bidding procurement, inquiry procurement, and direct contract procurement. (Lu & Liu, 2020) Multi-criteria evaluation is therefore valuable because it structures comparison and prioritization, but its practical use still depends on the procurement context, the type of item being sourced, and the decision situation under review. (Lu & Liu, 2020)

2.6.4. Supplier Segmentation and Criticality-Based Assessment Logic

Supplier segmentation differs from the previous assessment approaches because it does not primarily score isolated risks or compare suppliers criterion by criterion. Instead, it groups purchases into categories that can be managed differently. Airbus-related evidence states that purchasing policy is developed in accordance with a “strategic segmentation of purchases,” and that this segmentation is often based on the technological nature of component families while also integrating suppliers’ technological competences and competitor-related risks. (Mazaud, 2019)

This logic becomes more concrete once the key priorities of each segment are defined. The same source notes that the “key success factors for each segment have to be determined (costs, quality, lead time, related services, etc.),” after which “an individual strategy is then developed for each segment,” ensuring consistency with the firm’s overall strategy. (Mazaud, 2019) In that sense, segmentation is useful because it translates heterogeneous supply exposure into differentiated sourcing and management policies rather than treating all purchases alike.

A related assessment logic appears in MRO environments through explicit criticality classification. In the Cathay Pacific case, spare parts were not only categorized by function, but also subdivided into critical and non-critical components, with further criticality codes assigned to them. The distinction is substantive, since critical components were described as parts “essential to operating an aircraft safely and effectively,” whereas non-critical components covered parts not required for the safe and effective operation of the aircraft. (Yen, 2009)

2.6.5. Assessment Criteria: Criticality, Substitutability, Lead Time, and Concentration

Once supplier assessment moves beyond general models, its usefulness depends on the criteria used to judge the significance of a supply risk. Criticality remains central because aerospace parts do not carry equal operational consequences. In the Cathay Pacific case, critical components were described as parts that were usually "very expensive and complex," and one example was the US$1 million Electronic Engine Controller. (Yen, 2009) This indicates that criticality functions not only as a technical classification, but also as an indicator of how severe the operational and financial consequences of shortage may become. (Yen, 2009)

Substitutability and lead time refine that assessment further. In MRO settings, substitutability depends partly on whether alternative approved sources exist, since one source explicitly notes that "MROs can diversify their supply chains by incorporating approved non-OEM suppliers." (Guinn et al., 2025) Lead time is equally important because, in military aviation, cannibalization is used especially when there is a "scarcity of supply sources of high-value components" or when needed items "have an extended lead time." (Al-Momani et al., 2020) The same material also notes that low-demand parts create pressure to reduce procurement cycle time while increasing stock supply, particularly when those items are used in larger and more expensive applications. (Al-Momani et al., 2020)

A further criterion is concentration. Globalization has increasingly led many competitors to rely on a "common set of suppliers," sometimes without realizing that they share a Tier 3 or 4 source until disruption occurs. (Shih, 2018) Although such concentration may create cost advantages through aggregated volume, it also increases vulnerability because several firms may ultimately depend on the same upstream supplier. Taken together, these criteria show that aerospace supplier assessment cannot stop at generic supplier scoring, but must ask how critical the item is, how readily it can be substituted, how long replenishment takes, and how concentrated the underlying supply base has become. (Shih, 2018)

2.6.6. Limitations of existing assessment models in aerospace and MRO contexts

A central limitation of existing assessment models is that many of them remain more suitable for relatively simple supply environments than for the complexity of aerospace networks. One aviation source states explicitly that traditional Supply Chain Management (SCM) “models and approaches are useful when the amount of data to be processed is relatively small and the complexity of the problem is low. But what about larger problems with a lot more data, like in case of the aircraft’s spare parts business?” (Madhwal & Panfilov, 2017) In aerospace, supplier-risk assessment therefore faces a structural difficulty: the network is too data-intensive, too interdependent, and too operationally sensitive to be captured fully by generic models alone. (Madhwal & Panfilov, 2017)

A second limitation appears when assessment models have to function inside MRO environments. Here, even more advanced digital approaches do not automatically translate into practical applicability, because one source notes that “technology adoption faces several challenges,” including “high initial investment costs,” “data security and privacy concerns,” “integration with legacy systems,” and “regulatory approval processes for new technologies.” (Ison, 2026) Existing models are therefore limited not only by what they assess, but also by whether they can be implemented under the technical, organizational, and regulatory conditions of aviation maintenance. (Ison, 2026)

For aerospace and MRO contexts, the main weakness of current approaches is therefore not that they are unusable, but that they remain incomplete when network complexity is underestimated, and implementation constraints are treated as secondary issues. (Ison, 2026)

2.6.7. Implications for a Structured Aerospace-Specific Assessment Framework

Taken together, the previous discussion suggests that an aerospace-specific assessment framework should not rely on one uniform supplier score. In the Airbus case, purchasing was divided into distinct categories such as aerostructures, equipment items, engine, and materials, while the current trend in general procurement was also treated separately. This indicates that a structured framework should begin with item or segment classification and only then apply the relevant assessment logic, because the strategic role, relationship structure, and sourcing conditions differ across purchasing families. (Mazaud, 2019)

A second implication is that supplier assessment should be embedded in a coordinated decision structure rather than treated as an isolated procurement task. Airbus-related evidence notes that "cross-functional teams – the Multi-Functional Teams (MFT) – manage the purchasing activities of a given segment in a flexible way," with the aim of increasing efficiency and reducing procurement costs. (Mazaud, 2019) For aerospace assessment, this suggests that the framework should combine technical, commercial, and supply perspectives instead of reducing evaluation to a single functional viewpoint. (Mazaud, 2019)

Finally, the framework must also remain applicable to MRO-related decisions. In that context, one source notes that organizations can diversify their supply chains by "incorporating approved non-OEM suppliers." (Guinn et al., 2025) This implies that an aerospace-specific framework should not assess only the exposure attached to the current supplier, but also whether approved alternatives exist, especially where maintenance support depends on constrained or highly concentrated sources. (Guinn et al., 2025)

2.7. Risk Mitigation Strategies in Aerospace Supply Chains

2.7.1. Sourcing and Supplier-Base Strategies

Sourcing and supplier-base strategies represent the first mitigation layer because they determine whether risk remains concentrated in one supplier, one region, or one contractual relationship. At the general supply-chain level, supplier diversification is treated as a practical response to disruption exposure. One extracted study identifies the preparation of contingency and risk plans, supplier diversification through dual sourcing, and a preventive risk budget as the most appropriate measures for preventing stockouts during supply disruption. (Romana et al., 2023)

In aerospace supply chains, however, this logic must be adapted to the specific structure of aircraft manufacturing rather than transferred as a simple 'more suppliers' approach. One aerospace source describes a supply chain dilemma in which the absence of long-term strategic partners and the use of relatively single supplier structures can weaken performance; in the case of the Chinese aircraft ARJ21 (today known as Comac C909), single-supplier arrangements for airframe components and airborne finished products were associated with limited competition, poor quality, and high prices. This suggests that supplier-base mitigation requires two complementary directions: alternative sources where feasible, and stronger long-term supplier relationships where specialized capability cannot easily be substituted. (Lu & Liu, 2020)

The need to combine qualified alternatives with deeper supplier relationships makes strategic partnerships a second central sourcing strategy in aerospace manufacturing. Where supplier substitution is difficult, mitigation cannot rely only on adding further suppliers; it must also ensure that selected suppliers are capable of carrying broader technical and coordination responsibilities. Airbus-related evidence shows that first-tier suppliers are coordinated according to the strategic nature of their skills, and that "the more this expertise complements Airbus' core competences, the more this relationship will be of the partnership type (Risk Sharing Partner)". (Mazaud, 2019) This indicates that strategic partnerships can mitigate technological and development risk by placing complex subsystem responsibilities with suppliers that possess the required competences. At the same time, this sourcing model also creates interdependence, because supplier delays, capability gaps, or coordination problems may still affect the wider aircraft program. Sourcing strategy should therefore distinguish between broader supplier-base diversification for more substitutable items and strategic partnership models for complex systems where supplier knowledge is central to successful integration. (Mazaud, 2019)

Risk-sharing arrangements extend the partnership logic by making selected suppliers part of the program's development and execution structure rather than treating them only as component providers. The Boeing 787 example illustrates this shift: one source states that the program used a "global supply chain" model in which 90% of aircraft components were made by suppliers, while Boeing remained responsible only for a few production tasks and final assembly. (Lu & Liu, 2020) This indicates that risk-sharing and outsourcing can reduce the OEM's direct manufacturing burden, but also increase dependence on supplier performance. A comparable mitigation logic is visible in the A350 XWB case, where Airbus focused the development and production of larger components with Tier 1 suppliers in a pre-integration phase, which reduced work time with second- and third-tier suppliers for raw-material procurement and minor issues. Risk-sharing partnerships therefore mitigate some financial, technological, and workload-related pressures, but they also require clearer work-package responsibility, close supplier oversight, and active coordination of supplier performance. (Daniela, 2021)

Because risk-sharing and pre-integration move important responsibilities toward external partners, supplier-base strategy must also include supplier capability management. In the Boeing 787 case, one source identifies a major risk in the "usage and application of new technologies and materials by suppliers," because such decisions can create uncertainty in the certification process when outsourced components are not tested appropriately for aerospace application. (Wendt, 2016) The same source also points to the risk of inexperienced supply chain management teams on both the OEM and supplier side, especially where cultural differences, unclear responsibilities, and coordination challenges exist across the global supplier network. Supplier development should therefore be understood as a mitigation strategy in its own right: it is not only about increasing supplier capacity, but also about strengthening testing discipline, certification readiness, process maturity, and coordination capability among strategically important suppliers. (Wendt, 2016)

The sourcing logic differs in MRO environments. In aircraft maintenance, supplier-base strategy is less focused on development work packages for new aircraft programs and more closely connected to access to specialized maintenance providers, outsourced service capability, and continuity of support. One MRO-related source states that, "as airlines seek to reduce costs, optimize operations, and access specialized expertise, MRO outsourcing has become an increasingly prevalent strategy." (Ison, 2026) For mitigation purposes, this means that MRO organizations must treat external providers as part of the resilience structure: outsourcing can expand access to capabilities that are difficult to maintain internally, but it also makes provider reliability, technical competence, and service continuity central sourcing concerns. (Ison, 2026)

2.7.2. Inventory, Buffering, and Spare-Parts Availability Strategies

Inventory, buffering, and spare-parts availability form the second mitigation layer because sourcing alternatives alone do not ensure continuity if usable parts are not available at the required time. In aviation, this problem is especially visible in spare-parts supply chains, where inventory must protect operational availability while avoiding excessive capital lock-up. In the Cathay Pacific case, the total inventory value of aviation spare parts exceeded US$350 million, while dead and inactive stock accounted for 3% per year and had to be managed carefully due to obsolescence and unpredictable demand patterns. The same case also notes that spare-parts supply chain management was complex because it had to ensure the "timely service availability of a huge variety of stock" while also complying with strict quality and regulatory requirements. (Yen, 2009) This suggests that inventory buffering in aerospace cannot simply mean holding more stock. It requires a balance between availability, cost exposure, demand uncertainty, and compliance requirements. (Yen, 2009)

For MRO and maintenance-related environments, inventory mitigation therefore depends on adaptive inventory management rather than static stock levels. Evidence from military aviation identifies the need for an Adaptive Inventory Management System (AIMS) that eliminates shortcomings in the existing inventory system while remaining user-friendly and cost-effective. The same source states that such a system should include analytical capability for items with high failure rates and should reduce the probability of Aircraft on Ground events caused by supply problems. Its practical logic is to purchase the "correct amount and quantity needed, from the right seller, merchant or vendor, at the ideal time, with the most reasonable and least expensive price". (Al-Momani et al., 2020) In this sense, buffering is not only a physical inventory decision; it is also a planning and information problem in which demand signals, maintenance requirements, supplier performance, and item criticality must be linked to stock decisions. (Al-Momani et al., 2020)

A further mitigation route is to reduce dependence on physical inventory by using production-based availability options for selected spare parts. Additive Manufacturing (AM) is relevant here because it can shift parts of the buffer from stored components toward on-demand production capacity. One spare-parts supply-chain review indicates that AM-based spare-parts supply can improve aircraft supply-chain efficiency when demand characteristics, manufacturing and logistics lead time, and cycle service levels are considered together. The same source states that the "focus of inventory strategy with AM would be to reduce the safety stock of spare parts in the SC," particularly because additional safety stock in the aircraft industry can create substantial cost increases. (Mecheter et al., 2022) However, this does not mean that AM removes the need for inventory planning. The same extracted evidence also notes that spare-parts efficiency still depends on demand uncertainty, changes in supply potential, and material availability for printing. (Mecheter et al., 2022)

Taken together, inventory and buffering strategies mitigate aerospace supply risk by creating availability where sourcing strategies alone may be too slow. Physical spare-parts stocks remain necessary where unpredictable demand patterns, operational availability requirements, and stringent quality and regulatory requirements make immediate availability essential. (Yen, 2009) Adaptive inventory systems strengthen this logic by linking stock decisions more closely to failure behavior, vendor selection, purchasing timing, and AOG prevention. (Al-Momani et al., 2020) Additive manufacturing can complement this approach for suitable spare parts by reducing safety-stock requirements, but only where demand uncertainty, supply potential, and material availability make on-demand production feasible. (Mecheter et al., 2022) The next mitigation layer therefore concerns the network and coordination mechanisms through which these sourcing and inventory decisions are connected across suppliers, service partners, and aerospace supply-chain actors.

2.7.3. Network, Coordination, and Collaboration Strategies

Network, coordination, and collaboration strategies form the third mitigation layer because sourcing and inventory decisions only become effective when they are supported by reliable information flows, active supplier coordination, and clear problem-solving responsibilities. In aerospace manufacturing, this becomes especially important when complex work is outsourced and first-tier suppliers depend on smaller suppliers in their own networks. In the A350 XWB program, suppliers received detailed design tasks from Airbus, while Airbus also sent teams of engineers and technicians to provide technical advice and reduce bottleneck-related delays when suppliers faced pressure in producing more complex parts. The same source states that Airbus developed special supplier relationships to anticipate and mitigate potential problems and introduced a new way of working with suppliers known as “Extended Enterprise”. (Daniela, 2021) This suggests that coordination-based mitigation is not limited to formal work-package allocation; it also requires technical support, early problem identification, and collaborative intervention when supplier-side difficulties threaten program execution. (Daniela, 2021)

A central element of this coordination is visibility. In aircraft-parts supply chains, one source describes the purpose of supply chain management as ensuring that the “right product is produced at the right time and is at proper flow in the chain,” while noting that this depends on transport mode and inventory availability. (Madhwal & Panfilov, 2017) For mitigation purposes, this means that network coordination must connect inventory planning, supplier relationships, production execution, delivery, and testing rather than treating them as separate activities. The same source also suggests that aviation supply-chain networks should allow the involved parties to trace the path of supply when errors occur, monitor progress, and plan future manufacturing activities. Such visibility helps reduce the risk that problems remain hidden until they appear as delays, shortages, or quality failures. (Madhwal & Panfilov, 2017)

Digital coordination mechanisms can strengthen this visibility, although they should not be treated as a substitute for organizational coordination. In the same aircraft-parts context, proposed Industry 4.0 design principles include interoperability between supply-chain actors, information transparency across process levels, technical assistance for decision-making, and decentralized decisions by individual companies. The principle of ‘Information Transparency’ is especially relevant because it is described as the ability to show processes at each level so that, when changes occur within the chain, users are updated with the new details. In this sense, transparency functions as a mitigation mechanism because it supports earlier detection of deviations, clearer communication across tiers, and faster coordination of corrective action. (Madhwal & Panfilov, 2017)

For MRO environments, network coordination has a stronger service-continuity dimension. Maintenance activities are not only dependent on parts availability, but also on the integration of maintenance data, diagnostic information, and planning decisions across the MRO value chain. Evidence from Aircraft Maintenance 4.0 explains that digital maintenance systems can make diagnoses, predict failures, and establish maintenance plans, while data consolidated from multiple sources and transmitted wirelessly enables airlines to gain new insights and implement predictive maintenance. This suggests that network coordination in MRO increasingly depends on connecting operational, technical, and maintenance information before disruptions appear as delays, downtime, or spare-parts shortages. (Tsakalerou et al., 2022)

Taken together, network, coordination, and collaboration strategies mitigate aerospace supply risk by improving visibility, aligning responsibilities, and connecting actors that otherwise operate across separate tiers, regions, and functional domains. In aircraft-parts supply chains, visibility supports mitigation by enabling involved parties to trace the supply path when errors occur, monitor progress, and plan future manufacturing activities. (Madhwal & Panfilov, 2017) In aircraft manufacturing, coordination also requires active supplier support, as shown in the A350 XWB program, where Airbus sent engineering and technical teams to suppliers to provide advice and reduce bottleneck-related delays. (Daniela, 2021) In MRO, the emphasis shifts toward integrating maintenance data, diagnostic information, and predictive planning across the maintenance value chain. (Tsakalerou et al., 2022) However, coordination alone does not guarantee resilience when disruptions require rapid changes in capacity, routing, or operating procedures. This leads to the final mitigation layer: flexibility and continuity strategies.

2.7.4. Flexibility and Continuity Strategies

Flexibility and continuity strategies form the final mitigation layer because even diversified sourcing, inventory buffers, and network coordination cannot prevent every disruption. Their purpose is to preserve the ability to act when the original sourcing route, supplier capacity, maintenance plan, or logistics channel no longer functions as expected. A crisis-oriented aviation management source emphasizes that managers should prioritize rapid decision-making, bold adaptation, reliable execution, and impact-focused engagement during periods of disruption. In the context of aerospace supply chains, this suggests that flexibility is not only a structural property of the network; it also depends on decision-making routines that allow organizations to adjust priorities quickly while still protecting operational reliability. (Alomar & Abdallah, 2022)

For MRO environments, continuity is closely connected to the ability to move from reactive crisis handling toward controlled resource allocation. One aviation crisis-management source argues that increasing MRO activity can turn a maintenance organization from "firefighting mode" toward "management by exception mode," but that this requires careful planning of available resources across different crisis stages and the intended short-term operations. (Alomar & Abdallah, 2022) This indicates that continuity strategies in MRO must include resource planning, workload prioritization, and short-term operating scenarios rather than relying only on spare-parts stock or supplier access. Where disruption affects maintenance capacity, the relevant question is therefore not only whether parts are available, but whether manpower, hangar capacity, repair capability, and decision authority can be aligned quickly enough to keep maintenance operations functioning. (Alomar & Abdallah, 2022)

Transport and routing flexibility represent a further continuity mechanism, especially where aerospace suppliers, component flows, or spare-parts logistics depend on long-distance routes. Evidence on international trade and logistics shows that during the COVID-19 pandemic, China–Europe transport routes became especially important, particularly the rail corridor through Russia, Belarus, and Poland. Following the boycott of Russia, however, this route was no longer dominant; the extracted source states that some companies re-routed products to alternative rail routes, while most reverted to ocean freight, which increased the time required to bring goods to market. For aerospace supply chains, this illustrates that routing flexibility can preserve continuity, but it may also create new time and cost trade-offs. Alternative transport routes are therefore not a complete solution; they must be planned together with lead-time expectations, inventory buffers, and supplier prioritisation. (Cekerevac & Bogavac, 2023)

Overall, flexibility and continuity strategies complement the previous mitigation layers by creating response capacity when normal sourcing, inventory, and coordination mechanisms are insufficient. For manufacturing and spare-parts flows that depend on long-distance logistics, continuity may require alternative routing when established transport corridors are disrupted. In MRO settings, the emphasis is more directly linked to service continuity, maintenance capacity, short-term resource planning, and the avoidance of uncontrolled firefighting. (Alomar & Abdallah, 2022)

2.8. Localization, Reshoring, and Regionalization Strategies

2.8.1. Conceptual Distinctions and Strategic Role of Localization Strategies

Localization, reshoring, nearshoring, and regionalization should not be treated as interchangeable terms. In this review, localization is used as the broader strategic category for placing production, supply, or support capability closer to the relevant market, aircraft program, or operational region. Reshoring is more specific. One extracted definition describes the "reshoring" phenomenon as "the decision to relocate a manufacturing activity either back to the home country (back-reshoring) or to a nearby country that belongs to the same macro-region (near-shoring)." (Barbieri et al., 2020) This distinction is important because a company may strengthen regional resilience without fully returning production to its original home country. Nearshoring therefore represents a more limited geographical reconfiguration than back-reshoring, while regionalization refers to the broader organization of supply capacity within a macro-region rather than within one national boundary. This is particularly relevant because attracting an entire supply chain into one country may be difficult, whereas cooperation between countries in close macro-regions can support near-shoring initiatives. (Barbieri et al., 2020)

The strategic role of these concepts also differs from traditional offshoring logic. Offshoring is commonly associated with cost reduction and market-seeking motives, whereas reshoring can be triggered by several overlapping factors. In the literature, reshoring is described as being driven by “several, and possibly co-existing reasons,” with cost and operations forming important motivation groups and product quality appearing as a particularly frequent individual driver. (Barbieri et al., 2020) This suggests that reshoring and localization are not only geographical decisions, but also strategic reconfiguration decisions. They may respond to changed external conditions, unexpected problems in the existing global footprint, or the need for broader strategic realignment. For the purpose of this dissertation, localization strategies are therefore not understood as a simple reversal of globalization, but as possible responses to supplier risk, operational vulnerability, and the limits of globally dispersed sourcing structures. (Barbieri et al., 2020)

In aerospace, these conceptual distinctions matter because supplier capability is rarely confined to one local production system. Even where aerospace activity is concentrated around a major OEM or systems integrator, the relevant knowledge base and supplier relationships often extend across national and regional boundaries. The Boeing example illustrates this clearly: major aircraft sections and components are not sourced only from the immediate assembly region, but from other parts of the United States and, increasingly, from international suppliers. Aerospace knowledge flows are therefore not primarily local; they are described as “mostly international” and as “explicit and codified,” while also being distributed across independent firms and connected to markets for parts, components, and subassemblies. (Niosi & Zhegu, 2005) This means that localization in aerospace cannot simply be understood as placing all suppliers near the final assembly line. Rather, it must be assessed against the availability of specialized capabilities, the transferability of knowledge, and the existing structure of international supplier networks. At the same time, localization may still develop around strong industrial anchors, since “large firms dominate aerospace clusters and represent a magnet for suppliers.” (Niosi & Zhegu, 2005)

2.8.2. Resilience Rationale: Lead-Time, Control, Visibility, and Risk Exposure

The resilience rationale for localization and regionalization begins with the exposure created by globally dispersed supply structures. The COVID-19 crisis made this exposure visible because many firms experienced “dramatic exposure to supply chain disruptions” during the pandemic and lockdowns due to their reliance on offshore supplies. (Barbieri et al., 2020) In this sense, localization does not primarily represent a return to national production for its own sake. Rather, it responds to the realization that remote sourcing may create hidden vulnerability when transport, production capacity, political access, or supplier availability become unstable at the same time. The literature therefore suggests that managers can no longer focus only on efficiency and growth while giving insufficient attention to risk-related practices. (Barbieri et al., 2020)

From a resilience perspective, the main advantage of localization is the potential to reduce the distance between critical supply capability and the point where demand, assembly, or operational support arises. Shorter geographical and organizational distance can support faster reaction, easier coordination, and stronger managerial control when disruption occurs. However, this does not mean that localization automatically eliminates risk. One source stresses that reshoring may emerge either as a reaction to changed contextual conditions, unexpected problems in the firm’s global footprint, or as a broader move toward strategic realignment. This is important for aerospace because localization should not be interpreted as a purely operational measure. It is better understood as a structural response that may change the options available to the firm when disruption occurs. (Barbieri et al., 2020)

In aerospace manufacturing, the control argument is closely connected to the way OEMs structure their supplier base and coordination systems. Evidence from the Airbus-related supply chain context shows that a firm may centralize purchasing, consolidate its supplier base, and organize logistics centers to coordinate supplier-owned stock delivered to factory sites on a just-in-time (JIT) basis. This illustrates that resilience-oriented control does not depend only on the physical location of suppliers, but also on who coordinates the flow of material, who controls inventory positioning, and how supplier interfaces are governed. This suggests that the control benefits often associated with localization or regionalization should not be attributed to geographical proximity alone. In aerospace manufacturing, such benefits depend on whether the supply structure also provides clear procurement responsibility, coordinated logistics flows, controlled inventory arrangements, and effective supplier-base governance. (Pritchard & MacPherson, 2007)

At the same time, aerospace limits any simple lead-time or visibility argument because the sector remains strongly international. One literature source states that aerospace clusters show "strong international connections rather than local ones," while materials exchange inside clusters becomes less important when international outsourcing of large subassemblies gains importance in the product life-cycle strategy of firms. (Niosi & Zhegu, 2005) This means that a localized final assembly environment may still depend on critical suppliers, technologies, and subassemblies located elsewhere. This suggests that regionalization can reduce exposure only where the relevant supplier and knowledge capabilities are actually available within the chosen region; otherwise, the final assembly environment may appear local while important dependencies remain international. (Niosi & Zhegu, 2005)

The resilience rationale for localization is therefore selective rather than universal. Localization may reduce exposure where offshore dependence has become a significant vulnerability and where critical supply capability can realistically be positioned closer to the relevant aircraft program or production environment. (Barbieri et al., 2020) However, aerospace supply chains cannot easily be compressed into one region, since knowledge flows, specialized suppliers, and major subassemblies often remain internationally distributed. (Niosi & Zhegu, 2005) For this reason, the strategic value of localization depends less on geographical proximity alone and more on whether proximity actually improves control over critical supply interfaces, strengthens response capability, and reduces exposure to supplier or regional disruption.

2.8.3. Trade-Offs and Comparison with Diversification or Dual Sourcing

Localization must be evaluated as a trade-off rather than as an automatic improvement over global sourcing. For new supply-chain designs, managers must decide which activities should be produced internally, which should be sourced from suppliers, and where production or sourcing should take place. Location choice is therefore tied to tradability, transport cost, inventory carrying cost, value density, labor cost, and the feasibility of producing remotely. From this perspective, localization may reduce exposure to distant disruption, but it can also remove cost advantages that originally justified global sourcing. The cost logic behind offshoring is captured clearly in the observation that "work is frequently moved in search of lower-cost labor." (Shih, 2018)

In aerospace, the trade-off is more complex because supplier location is not only a cost variable, but also a capability variable. Some critical competences may exist outside the OEM's home region and may not be easily reproduced locally. The Boeing 787 example illustrates this problem: Japan's technological leadership in composites was one reason why Boeing contracted a large share of the aircraft's composite work to Japanese suppliers, and the required technology and process improvements went "far beyond raw material requirements." (Pritchard & MacPherson, 2007) This limits the strategic appeal of localization where regional suppliers cannot provide equivalent know-how, process maturity, or the required production capability. Local aerospace clusters may still support parts of the supplier base, but one source notes that "most knowledge transferred is not strategic," especially where clusters mainly gather small and medium-sized enterprise (SMEs) around larger assemblers for less critical parts and manufacturing knowledge. (Niosi & Zhegu, 2005)

Diversification and dual sourcing therefore remain important alternatives because they can reduce dependency without requiring the full relocation of production capability. However, in aerospace, diversification through international risk-sharing can also introduce strategic exposure. Aircraft programs based on system integration can support "risk reduction, market penetration, the containment of launch costs," and the use of foreign risk-sharing partners to access foreign government funding. (Pritchard & MacPherson, 2007) Yet the same source warns that "the financial advantages need to be balanced against broader economic and strategic concerns," including the erosion of Western commercial aircraft capability and rising foreign content. (Pritchard & MacPherson, 2007) In other words, international diversification may reduce short-term financial and program risk, while also increasing long-term dependence and weakening strategic industrial capability.

A further trade-off concerns scale and inventory efficiency. If localization is interpreted as placing more stock or capacity in multiple regional locations, it may increase responsiveness, but it can also raise the cost of duplicated inventory or unused capacity. One source highlights that firms serving dispersed geographic markets must decide where to physically store inventory, and that leftover inventories can create costs when supply and demand do not match. By contrast, inventory pooling allows multiple geographically dispersed markets to be served from one stock of inventory, using the aggregation of uncertain demand to reduce stockout risk and lower total inventory needs for a given service level. This suggests that a centralized, diversified, or pooled structure may sometimes be more efficient than a fully localized one, especially where demand is uncertain, volumes are limited, or spare capacity would be expensive to duplicate across regions. (Shih, 2018)

Overall, localization, diversification, and dual sourcing should be compared according to the specific risk mechanism. Localization is more relevant when geographical exposure and response time dominate. (Barbieri et al., 2020) Diversification or dual sourcing may be more suitable when the main vulnerability is supplier concentration and equivalent capability exists elsewhere. (Pritchard & MacPherson, 2007)

2.8.4. Manufacturing Localization versus MRO Support Localization: Decision Conditions

Manufacturing localization should be treated as a long-term operations decision rather than a simple geographical sourcing adjustment. If substantial capital has already been invested offshore, reshoring may need to wait until that investment has generated the expected return. In addition, reshoring decisions can be connected with "technology decisions, capital investments and changes in capacity" as part of a broader operations strategy. (Barbieri et al., 2020) For aircraft manufacturing, localization is therefore most convincing when the benefits of changing the supply structure outweigh the investments, capacity choices, and future options that such a decision may limit or affect. (Barbieri et al., 2020)

MRO support localization follows a different logic. It does not necessarily require relocating aircraft production or major component manufacturing; instead, it concerns the regional positioning of repair capability, maintenance capacity, approved service providers, and spare-parts support. In this context, the question is closer to a make-or-buy and where-to-repair decision. The decision to outsource aircraft maintenance is complex because it involves "cost, quality, safety, and regulatory compliance," and that make/buy models are used to determine whether maintenance should be performed in-house or outsourced. (Ison, 2026) Regionalizing MRO support capability is therefore justified only where the selected region or provider can meet cost expectations, quality requirements, safety standards, regulatory approval needs, and operational responsiveness at the same time. (Ison, 2026)

By contrast, MRO support localization can also be shaped by maintenance-cost geography. The evidence notes that "labor costs, a significant portion of MRO expenses, vary considerably across different regions." (Ison, 2026) A cited study further found that labor costs for heavy-maintenance visits in China were less than half of those in the United States, with estimated savings of US$1 million per aircraft annually. This shows that regionalizing MRO support capability is not automatically a resilience decision; it may also be driven by cost differences between maintenance locations. For the later framework, MRO support localization should therefore be assessed according to whether the regional footprint improves continuity, turnaround responsiveness, and cost exposure at the same time, rather than only whether maintenance can be performed in a lower-cost region. (Ison, 2026)

2.9. Digital Transformation of Aerospace Supply Chains and MRO Networks

2.9.1. Digitalization as a Strategic Driver of Supply Chain Resilience

Following the discussion of localization, digital transformation represents a different but complementary resilience response. Localization changes where critical capability is positioned; digitalization changes how quickly information is captured, interpreted, and translated into decisions. Its strategic relevance therefore lies in reducing the gap between disruption signals and managerial response. In supply chain planning, recent information technologies have moved firms from decisions based mainly on intuition and experience toward more automated and data-driven methods, while current LLM (Large Language Model)-based systems are presented as a way of reducing decision cycles from “days and weeks to minutes and hours.” (Linton et al., 2025) For aerospace supply chains, where supplier risk can affect production continuity, spare-parts availability, and MRO responsiveness, digitalization should therefore be understood as decision infrastructure rather than as an isolated operational tool. (Linton et al., 2025)

At the same time, digitalization should not be treated as an automatic substitute for supply-chain design, supplier strategy, or contingency planning. One disruption-mitigation source states that “planning, management, technology, and innovation need to be always present in the short, medium and long term,” but the same source also ranked AI, maximum blockchain integration, and warehouse robotics among the least relevant measures for preventing stockouts when compared with organizational measures such as contingency planning and supplier diversification. (Romana et al., 2023) This indicates that digital tools create resilience value only when they are embedded in broader managerial routines, risk governance, and supplier-response structures. In this chapter, digital transformation is therefore positioned as an enabling layer that supports risk monitoring, traceability, forecasting, spare-parts planning, and scenario-based decision-making, rather than as a stand-alone solution to aerospace supply vulnerability. (Romana et al., 2023)

2.9.2. Data Visibility, Integration, and Real-Time Supply Chain Monitoring

Digital resilience first depends on whether relevant supply-chain data can be made visible and usable across operational decision points. In aerospace, this is particularly important because disruption effects may emerge in supplier capacity, transport availability, material shortages, spare-parts demand, or MRO support capability before they become visible in final production or fleet operations. Recent LLM-based planning tools illustrate this shift by allowing planners to ask operational questions such as “How much raw material of type T does supplier S have today?” and by translating such questions into data queries connected to a company’s internal data repository. (Linton et al., 2025) This does not remove the need for structured planning systems, but it changes how quickly planners can access and interpret the current state of the supply chain. The same source also indicates that LLMs can explain system decisions and provide trend-based insights, which makes digital visibility relevant not only for data access, but also for understanding why a planning recommendation or supplier-related warning has emerged. (Linton et al., 2025)

Real-time monitoring extends this visibility from internal planning systems toward the physical movement, condition, and status of supply-chain flows. The extracted aviation-related blockchain source describes a smart SCM vision in which sensors, ICT (Information and Communication Technology), Big Data, IoT, and Blockchain are used to monitor supply-chain status and build data-driven models of supply chains or systems of supply chains. (Madhwal & Panfilov, 2017) This connects directly to aerospace and MRO contexts, where the practical problem is not only whether a part exists somewhere in the network, but whether its status, movement, condition, and approval pathway can be understood quickly enough to prevent production delay or aircraft downtime. In the broader digital supply-chain literature, IoT devices such as sensors and RFID (Radio-Frequency Identification) tags are described as tools for tracking goods, monitoring inventory levels, and collecting data on product condition during transit; this "real-time visibility" enables faster responses to transportation delays, stockouts, and quality issues. (Holloway, 2025) For aerospace supply chains, data integration and monitoring therefore form the operational base on which the more specific digital tools discussed in the next subsection can create value. (Holloway, 2025)

2.9.3. Digital Technologies for Risk Monitoring, Traceability, Spare-Parts Supply, and Maintenance Support

Artificial Intelligence (AI) and **Machine Learning (ML)** provide the analytical layer of digital supply-chain resilience. Their main contribution is not simply automation, but the ability to process large data volumes in order to detect patterns, forecast demand, and support faster operational decisions. One source states that the integration of deep learning and machine learning in supply chain management has "transformative potential," while further adoption is described as essential for managing increasing supply-chain complexity. (Khedr & S, 2024) In practical terms, machine-learning algorithms can support demand and sales estimation, synchronize production schedules and inventory levels with expected market demand, and reduce both stockouts and excess inventory. (Khedr & S, 2024) For supplier-risk and disruption management, AI-driven solutions are also linked to the prediction of demand fluctuations, identification of potential supply-chain risks, optimization of inventory, prediction of transportation delays, detection of production bottlenecks, and recommendations for alternative sourcing strategies. (Holloway, 2025)

Blockchain addresses a different problem: the reliability and traceability of information across fragmented supply chains. In aircraft-parts supply chains, where components may pass through several tiers, repair points, logistics providers, and approval steps, traceability depends on whether information can be verified across organizational boundaries. One aviation source defines blockchain as a system that dynamically incorporates real-time transactions into chains of blocks and notes that "Information on a Blockchain exists as a shared database which isn't stored in any single location, meaning the records it keeps are truly public and easily verifiable." (Madhwal & Panfilov, 2017) Its relevance for aerospace lies in the ability to record and verify part-related information such as serial numbers, validity, authenticity, and uniqueness through smart-contract logic. Blockchain is therefore less a general efficiency tool than a potential trust infrastructure for aircraft-parts visibility, traceability, and transaction verification. (Madhwal & Panfilov, 2017)

Additive Manufacturing (AM) changes the spare-parts discussion by shifting part of the supply logic from physical inventory toward digital design and localized production capability. In aerospace, AM is already presented as having moved beyond prototyping, with Airbus and Boeing both active in component-part AM across military and commercial aircraft models. One source states that AM "makes it possible to have objects printed in remote locations as delivery of goods is no longer a restriction," which links the technology directly to lead-time reduction, lower inventory needs, and reduced dependence on physical shipment routes. (Attaran, 2017) However, AM should not be presented as a complete replacement for conventional spare-parts supply. A systematic review on AM for spare parts states that its adoption is growing, but that it is "not considered a replacement for conventional spare parts supply and conventional SCs"; instead, it is considered a complementary measure for spare-parts management. (Mecheter et al., 2022) For aerospace, this makes AM most relevant where selected parts can be produced reliably, where demand variability is high, and where a mixed sourcing logic combining AM and conventional manufacturing improves service level and responsiveness. (Mecheter et al., 2022)

Predictive Maintenance and **Maintenance 4.0** shift digital transformation from the supply chain into the operational maintenance environment. In MRO, digitalization and data analytics are described as transforming how maintenance services are delivered and managed, while cloud computing, IoT, and AI enable providers to optimize maintenance operations, improve efficiency, and reduce costs. Cloud computing supports real-time data sharing between airlines and MRO providers, IoT sensors provide aircraft performance and health data, and AI tools support diagnostics, troubleshooting, and anomaly detection. Predictive maintenance and reliability-centered maintenance are therefore important because they allow maintenance actors to use sensors, data analytics, and AI to anticipate potential failures and optimize maintenance schedules. For MRO networks, this supports reduced downtime, fewer operational disruptions, and the preservation of aircraft airworthiness. (Ison, 2026)

Digital Twins add a scenario-modelling and decision-support layer to the digital supply-chain architecture. They are described as virtual representations of physical assets, processes, or systems that allow companies to simulate and analyze supply-chain scenarios without disrupting actual operations. This is relevant because aerospace supply-chain decisions often involve trade-offs between inventory, transport routes, supplier alternatives, maintenance capacity, and operational continuity. Digital twins can provide a comprehensive real-time view of a supply chain, allow managers to visualize potential risks, and support decisions based on simulated outcomes. By creating a digital replica of the supply chain, companies can identify inefficiencies, predict failures, and develop contingency plans before a disruption affects production or maintenance execution. In this sense, digital twins support not only monitoring, but also structured preparedness and scenario-based response planning. (Holloway, 2025)

2.9.4. The Role of Digital Transformation in Enabling Resilience, Localization, and MRO Performance

Digital transformation links the previous resilience strategies by improving the connection between visibility, assessment, and action. Its contribution is strongest where digital tools help organizations move from isolated monitoring toward integrated decision support. LLM-based technology is expected to support “end-to-end decision-making scenarios,” while also allowing firms to automate supply-chain processes and integrate trade and forecasting processes. (Linton et al., 2025) However, this capability is not automatic. The same source stresses that LLM-based supply-chain optimization requires precise language, user training, and managerial understanding of system capabilities and limitations. For the thesis framework, this means that digital transformation should be treated as an enabling mechanism for supplier-risk monitoring and response decisions, not as a replacement for structured supplier assessment, contingency planning, or managerial judgement. (Linton et al., 2025)

Digitalization also affects the feasibility of localization and regionalization strategies. Additive manufacturing is especially relevant because it can reduce the need to move every physical part through long and complex supply chains. One aviation-focused AM source states that "AM applications made supply chains more elastic, bringing manufacturing closer to the assembly, utilization and MRO location." (Romero & Vieira, 2015) The same source links this to fewer transportation requirements for parts and components, changes in production and MRO flows, lower logistics costs, and the possibility that some aircraft parts no longer need to be transported from remote countries to final assembly locations. (Romero & Vieira, 2015) At the same time, AM-based localization remains conditional. Spare-parts supply through AM still depends on demand uncertainty, material availability, raw-material sourcing, technology suppliers, and the decision whether single sourcing, dual sourcing, or competitive sourcing is appropriate for the AM material base. Digital localization is therefore not simply a matter of printing parts locally; it requires alignment between part criticality, material supply, certification feasibility, technological capability, and MRO responsiveness. (Mecheter et al., 2022)

2.10. Research Gap and Implications for the Thesis Framework

The preceding literature review has shown that aerospace supply-chain resilience is not an unexplored topic. Existing research covers disruption exposure, supplier risk, risk assessment, sourcing and mitigation strategies, localization, MRO continuity, and digital transformation. The remaining gap therefore does not lie in the absence of these individual themes, but in their limited integration into one decision logic. Supplier selection is described as an important process because it uses significant financial resources, affects organizational success, minimizes purchase risk, reduces purchasing costs, and supports long-term buyer–supplier relationships. (Khedr & S, 2024) However, for aerospace supply chains this is not sufficient on its own. Aircraft-parts supply involves interdependent manufacturers and strict requirements before parts can move forward in the chain; if these requirements are not met, parts may be returned, remanufactured, and delayed. (Madhwal & Panfilov, 2017) MRO spare-parts environments can also involve very large supplier and item structures, as shown by the Cathay Pacific case with more than 380,000 line items and over 2,300 suppliers. (Yen, 2009) This suggests that supplier risk assessment must be connected more directly to the different consequences of supplier disruption in aircraft manufacturing and MRO.

A first research gap therefore concerns the connection between supplier assessment and strategic response. The literature provides supplier-selection criteria, performance monitoring, scorecards, predictive analytics, and supplier-evaluation approaches, but these methods do not fully explain which strategic response should follow from a specific aerospace supplier-risk profile. (Khedr & S, 2024) In other words, a supplier may be assessed as critical, exposed, difficult to substitute, regionally vulnerable, or operationally important, but the available literature does not yet provide a sufficiently integrated framework for deciding whether the appropriate response should be supplier development, dual sourcing, inventory buffering, localization, regional MRO support, outsourcing adjustment, digital monitoring, or a combination of these measures. This is particularly important because manufacturing and MRO do not translate supplier disruption into the same consequences: manufacturing risk is often linked to program execution, assembly continuity, and coordination across suppliers, while MRO risk is more directly linked to aircraft availability, repair turnaround, approved parts, and service continuity.

A second gap concerns the way localization and digital transformation are discussed. Reshoring and nearshoring are treated as responses to changed supply-chain conditions, but one extracted source stresses that “two elements appeared to be critical in differentiating the type of responses, namely the time (short term vs. long term) and the decision-maker (single firm vs. supply chain)”. (Barbieri et al., 2020) This means that localization cannot be treated as a general resilience recommendation; it has to be evaluated according to the risk profile, the part or capability involved, the decision authority, the implementation horizon, and the wider supplier network. Digital tools create a similar issue. Machine learning and deep learning can support supplier evaluation, demand forecasting, inventory optimization, predictive performance assessment, and supply-chain decision-making, but their usefulness still depends on reliable data and on whether the generated insights can be translated into a clear managerial decision context. (Khedr & S, 2024) Additive manufacturing also shows that digital and localized response options may strengthen spare-parts supply, but mixed supply-chain configurations can be more effective than purely centralized or decentralized AM structures depending on demand frequency and technology maturity. (Mecheter et al., 2022) The gap is therefore not simply digital adoption, but the integration of digital support into supplier-risk and localization decisions.

The implication for this thesis is that the proposed framework should not be a general supplier scorecard or a simple list of mitigation strategies. It should translate supplier-risk assessment into conditional response logic. The framework should first identify the supplier-risk profile, including criticality, lead time, quality implications, component performance, repair capability, and MRO relevance. (Yen, 2009) It should also consider whether approved alternative suppliers or non-OEM sources are available in maintenance-related supply environments. (Guinn et al., 2025) Digital and information-related criteria should be included where supplier evaluation, predictive performance assessment, inventory optimization, and data-supported decision-making are relevant. (Khedr & S, 2024) The framework should then distinguish whether the consequence affects manufacturing continuity, MRO service continuity, or both. On that basis, it should connect the assessed risk to possible responses such as inventory buffering, supplier monitoring, repair-capability evaluation, and supplier relationship management. (Yen, 2009) Diversification or dual sourcing should also be considered as a mitigation option where supplier dependency creates vulnerability. (Romana et al., 2023) Localization or regionalization should be treated as a conditional strategic response whose feasibility depends on the decision horizon, decision-maker, and wider supply-chain configuration. (Barbieri et al., 2020) Finally, the framework should evaluate feasibility through cost, certification, capability, regulatory approval, data availability, and implementation effort. This research gap also justifies the empirical part of the dissertation: expert input is needed to assess which criteria practitioners consider most important and how feasible different response options are in real aerospace supply environments.

3. Methodology

3.1. Research Design and Methodological Logic

This dissertation follows a literature-based and empirical research design. The literature review provides the theoretical foundation by identifying the main concepts, risks, assessment criteria, mitigation strategies, localization and regionalization options, digital support mechanisms, and manufacturing – MRO differences relevant to aerospace supply chain resilience. The empirical part extends this foundation through an online expert survey, which is used to examine how these issues are perceived and prioritized in practice.

The research design can be described as a mixed-methods survey approach. Closed questions provide descriptive quantitative results, for example on disruption exposure, supplier-risk categories, assessment criteria, mitigation strategies, and the perceived relevance of localization, regionalization, and digital tools. Open questions complement this by allowing respondents to add qualitative expert insights, practical explanations, and additional recommendations.

This methodological logic follows directly from the research gap identified in the literature review. The gap is not that supplier risk, mitigation, localization, digitalization, or MRO continuity are absent from the literature, but that these areas are insufficiently integrated into one aerospace-specific decision logic. Therefore, the empirical part is used to collect structured expert input that supports the later development of a supplier-risk and strategic-response framework for aerospace manufacturing and MRO-related supply environments.

3.2. Survey Design and Questionnaire Structure

The empirical data for this dissertation was collected through an online questionnaire. The survey was designed to be mostly anonymous, concise, and suitable for professionals with limited available time. It was structured to take approximately 10 minutes and consisted mainly of closed questions, supported by a small number of open questions. Most closed questions used 5-point Likert scales in order to capture expert perceptions in a comparable form.

The questionnaire was derived from the themes developed in the literature review. It therefore follows the analytical logic of the dissertation: disruption exposure, supplier-risk perception, supplier-risk assessment criteria, mitigation strategies, localization and regionalization, digital tools, and the distinction between manufacturing and MRO-related supply environments. Instead of treating each survey question separately in the main text, the structure of the questionnaire is summarized in Table 3.1. The complete questionnaire, including all questions, answer options, and scale descriptions, is provided in the Appendix section.

Table 3.1.

Overview of Survey Sections, Main Focus Areas, and Analytical Purpose

Survey Section:	**Main Focus:**	**Purpose:**
Respondent profile	Role, organization type, manufacturing/MRO relevance	To classify respondent background
Disruption exposure	Pandemic, geopolitical, raw-material, logistics, capacity, certification, demand, and labor disruptions	To assess perceived disruption impact
Supplier risk perception	Operational, quality, financial, capacity, certification, logistics, visibility, single-source, and spare-parts risks	To identify dominant supplier risks
Supplier risk assessment criteria	Criticality, lead time, alternatives, concentration, certification, delivery reliability, visibility, and repair support	To evaluate relevant assessment criteria
Mitigation strategies	Diversification, dual sourcing, partnerships, buffers, contingency planning, localization, digital monitoring, and additive manufacturing	To assess effectiveness and feasibility of response options
Localization and regionalization	Manufacturing localization and MRO-support regionalization	To evaluate when regional or local responses are justified
Digital tools	Visibility tools, AI/ML, blockchain, predictive maintenance, digital twins, and additive manufacturing	To assess the role of digital support mechanisms
Final expert input	Open comments and recommendations	To collect qualitative practitioner insights

Note. Source: Author’s own illustration based on the questionnaire developed for this dissertation.

3.3. Target Respondents, Sampling, and Data Collection

The target respondents for the empirical part of this dissertation were professionals with practical exposure to aerospace supply chains. This included procurement and sourcing specialists, supply chain and logistics professionals, supplier quality or supplier development specialists, production and operations personnel, MRO and maintenance planning professionals, inventory and materials management personnel, as well as aviation consultants or other specialists with relevant industry knowledge. These respondent groups were selected because supplier risk, mitigation decisions, localization, digital tools, and MRO-related continuity issues are usually assessed by professionals with operational, analytical, or decision-making responsibility in these areas.

The sampling approach can be described as purposive expert sampling. The objective was not to achieve statistical representativeness of the entire aerospace industry, but to collect informed expert perceptions from respondents who are familiar with aerospace supply environments. This approach is suitable because the dissertation focuses on how relevant practitioners evaluate supplier risks, assessment criteria, mitigation strategies, and the practical feasibility of different strategic responses.

Data was collected through an online questionnaire distributed via professional networks, direct contacts, LinkedIn, and aviation-related outreach. This distribution method was chosen to reach respondents from different aerospace-related roles and organizations, including manufacturing, MRO, and mixed supply environments. The collected responses therefore provide practical input for the later analysis and framework development, while remaining limited to the perspectives of the participating expert sample.

3.4. Data Analysis Approach

The survey data will be analyzed using a descriptive and practice-oriented approach. Closed questions will be evaluated through frequencies, percentages, and average Likert-scale scores. This allows the analysis to identify which disruption factors, supplier-risk categories, assessment criteria, and mitigation strategies are considered most relevant by the respondents. Where appropriate, the results will also be ranked in order to show the relative importance or perceived effectiveness of different response options.

The analysis will not aim to apply complex statistical modelling. Instead, the purpose is to identify patterns, priorities, and feasibility perceptions that are relevant for the later development of the thesis framework. Where the number and composition of responses allow it, selected results may also be compared between respondents with mainly manufacturing, mainly MRO, or mixed aerospace supply-chain backgrounds. This can help show whether supplier risks and strategic responses are perceived differently across these supply environments.

Open questions will be analysed through a simple qualitative thematic approach. Similar answers will be grouped, recurring themes will be identified, and relevant expert comments will be compared with the findings from the literature review. In this way, the open responses support the interpretation of the quantitative survey results and provide additional practical context for the later discussion and framework development.

3.5. Ethical Considerations, Methodological Limitations, and Transition to Findings

Participation in the survey was voluntary, and the respondents were informed that the data would be used only for academic purposes within this dissertation. The questionnaire did not require sensitive company-internal information, and responses were treated confidentially. Where possible, the findings are presented in aggregated form in order to avoid linking individual answers to specific persons or organizations.

The empirical results are subject to several methodological limitations. The survey was available online from 30 March to 22 May 2026 and received 16 responses. This limited sample size restricts the extent to which the findings can be generalized to the wider aerospace industry. In addition, aerospace supply chain experts represent a specialized respondent group, which makes broad participation difficult. The results therefore reflect expert perceptions rather than statistically representative evidence or confidential company data. It is also possible that manufacturing and MRO-related perspectives are not equally represented within the sample.

Despite these limitations, the survey provides useful practical input for the objective of this dissertation. The findings can support the development of the later supplier-risk and strategic-response framework by indicating which risks, assessment criteria, mitigation strategies, localization or regionalization options, and digital tools are considered most relevant by the participating experts. The following chapter therefore presents and discusses the survey results as structured expert input rather than as statistically conclusive industry evidence.

4. Survey Results and Empirical Findings

4.1. Introduction to the Empirical Results

This chapter presents the results of the online expert survey as a practice-oriented extension of the literature review. Its purpose is not to test statistical hypotheses, but to identify how participating aerospace-related professionals perceive supplier risks, assessment criteria, mitigation strategies, localization options, and digital support mechanisms.

The analysis follows the structure of the questionnaire and reports the findings at question level and by thematic survey section. The results are therefore presented in an aggregated form. Individual response paths are not traced, and the chapter does not compare how specific respondent groups answered particular questions. This means that the findings are not interpreted as, for example, the view of one organization type or one specific supply environment. Instead, they are treated as combined expert perceptions from the participating sample.

Because the survey received 16 responses, the findings must be interpreted with caution. The sample provides useful practical insight into perceived priorities and feasibility considerations, but it cannot be regarded as statistically representative evidence for the aerospace industry as a whole. The value of the results lies mainly in their ability to indicate which risks, assessment criteria, and strategic responses are considered relevant by the participating experts. On this basis, the following sections present the empirical findings as structured input for the later discussion and framework development.

4.2. Survey Sections

- **Respondent profile:**

The survey received 16 valid responses. The first three questions were used to describe the background of the participating experts in terms of role, organization type, and relevant supply environment. The purpose of this respondent profile is not to establish statistical representativeness, but to show the professional scope of the expert input used in the empirical part of the dissertation.

Table 4.1.

Respondent Profile

Category:	Survey Results:
Current role	Supply Chain / Logistics (6); Procurement / Sourcing (3); Consulting / Advisory (3); Supplier Quality / Supplier Development (1); MRO / Maintenance Planning (1); Other (2) — After Sales; IT (Requirements Engineering)
Organization type	Aircraft OEM / Manufacturer (6); Consulting / Research / Other Specialist Organization (5); Airline (3); Independent MRO Provider (1); Distributor / Logistics Provider (1)
Relevant supply environment	Mainly Aircraft Manufacturing (5); Mainly MRO / Maintenance Support (2); Both Manufacturing and MRO (2); Other (7)— Aviation Strategies; Supply chain logistics and sourcing through air/road transportation; Suppliers of onboarding material; Supplier; IT; strategic procurement; Airbus Upgrade Business

Note. Source: Author's own table based on the empirical survey conducted for this dissertation (n = 16).

The respondent profile indicates that the sample includes perspectives from aerospace manufacturing, airline operations, MRO-related activities, logistics, procurement, consulting, and specialist organizations. The strongest role group is supply chain and logistics, followed by procurement or sourcing and consulting or advisory functions. In terms of organization type, aircraft OEMs or manufacturers form the largest group, followed by consulting, research, or other specialist organizations and airlines. The supply-environment responses also show that the sample is not limited to one operational context, as it includes manufacturing, MRO, mixed manufacturing–MRO, and other aerospace-related perspectives. Overall, the profile supports the use of the responses as descriptive expert input, while the limited sample size still requires cautious interpretation.

- **Disruption exposure in recent years:**

Question 4 examined how strongly different disruption factors affected the respondents' supply environments during recent years. The results are summarized in Table 4.2. The ranking is based on the average Likert score.

Table 4.2.

Perceived Disruption Exposure in Recent Years

Rank:	Disruption Factor:	Average Score:	High / very significant impact
1	Geopolitical conflict / sanctions	4.00	11 / 16
2	Supplier capacity constraints	3.69	11 / 16
3	Pandemic-related disruptions	3.50	8 / 16
4	Logistics / transport bottlenecks	3.38	10 / 16
5	Regulatory / certification constraints	3.19	9 / 16
6	Labor shortages	3.19	5 / 16
7	Raw-material shortages	3.00	6 / 16
8	Demand volatility	2.63	1 / 16

Note. Source: Author's own table based on Q4 of the empirical survey conducted for this dissertation (n = 16; 1 = no significant impact, 5 = very significant impact).

The results indicate that recent aerospace supply environments were affected by several overlapping disruption drivers. Geopolitical conflict and sanctions received the highest average score, followed by supplier capacity constraints. This suggests that disruption exposure is not perceived only as a temporary consequence of the pandemic, but also as a continuing issue linked to political instability, constrained supply capacity, and structural supply-side limitations.

Pandemic-related disruptions and logistics or transport bottlenecks also remain relevant in the responses. In addition, regulatory and certification constraints received a relatively high number of high-impact assessments, which is important in an aerospace context where supplier changes, alternative sourcing, and material substitution are often limited by approval requirements. By contrast, demand volatility received the lowest average score and only one high-impact assessment. Overall, the findings point toward a multi-causal disruption environment in which geopolitical, capacity-related, logistical, and regulatory factors are more dominant than demand-side volatility.

- **Supplier risk perception and disruption consequences:**

Question (Q) 5 examined how significant different supplier-risk categories are perceived to be in aerospace supply chains. The results show that no category was assessed as irrelevant overall. All listed supplier risks reached an average score above the midpoint of the scale, which indicates that supplier risk is perceived as a broad and multi-dimensional problem rather than as one isolated issue. The strongest average scores were recorded for logistics, transport, and lead-time risk, followed by operational or production risk. Quality risk, capacity risk, financial risk, information and visibility risk, single-source dependency, and spare-parts or repair-network dependency were also rated as relevant supplier-risk categories.

Table 4.3.

Q5 – Perceived Significance of Supplier-Risk Categories

Rank:	Disruption Factor:	Average Score:	Significant / very significant
1	Logistics / Transport / Lead-Time Risk	4.27	13 / 15
2	Operational / Production Risk	4.07	12 / 15
3	Quality Risk	3.81	11 / 16
4	Capacity Risk	3.80	9 / 15
5	Financial Risk	3.73	8 / 15
6	Information / Visibility / Coordination Risk	3.73	10 / 15
7	Single-Source Dependency Ris	3.73	9 / 15
8	Spare-Parts / Repair-Network Dependency Risk	3.67	9 / 15
9	Geopolitical / Location Risk	3.60	9 / 15
10	Regulatory / Certification Risk	3.40	8 / 15

Note. Source: Author’s own table based on Q5 of the empirical survey conducted for this dissertation (n = 15–16; 1 = not significant, 5 = very significant).

Question 6 asked respondents to identify the three supplier risks that currently create the greatest vulnerability in their organization or supply environment. The most frequently selected category was capacity risk, followed by geopolitical or location risk and single-source dependency risk. This indicates that the broad significance of supplier risks does not automatically translate into the same priority ranking when respondents are asked to identify the most pressing vulnerabilities. While logistics and lead-time risk received the highest average significance score in Question 5, the priority vulnerability question placed stronger emphasis on capacity, geopolitical exposure, and supplier dependency.

Question 7 then focused on the consequences of supplier disruption. The most frequently selected consequences were production delay and cost increase, followed by aircraft downtime or Aircraft-on-Ground risk, assembly interruption, and quality or compliance risk.

Table 4.4.

Greatest Vulnerabilities and Most Critical Consequences

Q6 – Greatest supplier vulnerabilities:	**Selections:**
Capacity Risk	10
Geopolitical / Location Risk	8
Single-Source Dependency Risk	7
Operational / Production Risk	4
Quality Risk	4
Financial Risk	4
Logistics / Transport / Lead-Time Risk	3
Information / Visibility / Coordination Risk	3
Spare-Parts / Repair-Network Dependency Risk	3
Regulatory / Certification Risk	2

Q7 – Most critical disruption consequences:	**Selections:**
Production Delay	9
Cost Increase	7
Aircraft Downtime / AOG Risk	7
Assembly Interruption	6
Quality / Compliance Risk	6
Program Instability / Planning Disruption	4
Reduced Service Level	3
Customer / Operator Impact	2
Maintenance Turnaround Delay	2

Note. Source: Author’s own table based on Q6 and Q7 of the empirical survey conducted for this dissertation (n = 16; multiple selections possible).

Overall, these findings indicate that supplier disruption is not perceived only as a procurement problem. It translates into production delay, cost escalation, assembly interruption, quality or compliance exposure, and aircraft downtime risk. The results therefore point toward a dual consequence structure: manufacturing continuity on one side, and MRO or service continuity on the other. This supports the later need for a framework that connects supplier-risk categories with their operational consequences instead of treating supplier risk as a general and undifferentiated threat.

- **Supplier risk assessment criteria and methods:**

Question 8 examined which criteria are considered important when assessing supplier risk in aerospace. The results show that supplier risk assessment is not based on one single factor, but on a combination of operational, supply-side, quality, visibility, and aerospace-specific criteria.

Table 4.5.

Q8 – Supplier Risk Assessment Criteria

Rank:	Assessment criterion:	Average Score:	Important / very important:
1	Delivery Reliability	4.40	14 / 15
2	Supplier Lead Time	4.27	13 / 15
3	Availability of Alternative Suppliers	4.20	12 / 15
4	Supplier Quality Performance	4.07	11 / 15
5	Component Criticality	3.93	11 / 15
6	Visibility / Data Transparency	3.87	10 / 15
7	Repair / Spare-Parts Support Capability	3.69	11 / 16
8	Certification / Approval Dependency	3.67	10 / 15

9	Financial Stability of Supplier	3.53	8 / 15
10	Geographic Location Exposure	3.47	7 / 15

Note. Source: Author's own table based on Q8 of the empirical survey conducted for this dissertation (n = 15–16; 1 = not important, 5 = very important).

Questions 9 and 10 show that supplier risk assessment is usually at least partly structured. Most respondents selected either a structured internal method or a partly structured method, while no respondent indicated that no formal method is used. For useful assessment approaches, the strongest selections were digital analytics or predictive tools, multi-criteria decision models, and a combination of several methods.

Overall, the results suggest that supplier risk assessment in aerospace should not rely on one single method. Instead, the findings support a combined approach based on structured criteria, supplier performance data, digital analytics, and decision-support logic.

Table 4.6.

Supplier Risk Assessment

Q9 – Formality of supplier risk assessment:	**Selections:**
Yes, a structured internal method	10
Yes, partly structured / partly informal	5
No formal method	0
Not sure	1

Q10 – Useful approaches for supplier risk assessment:	**Selections:**
Digital Analytics / Predictive Tools	10
Multi-Criteria Decision Models	9
Combination of Several Methods	9
Supplier Scorecards / KPI-Based Evaluation	7
Criticality Segmentation	3

Scenario Analysis	3
FMEA-Based Methods	2
Expert Judgment Panels	2

Note. Source: Author's own table based on Q9 and Q10 of the empirical survey conducted for this dissertation (n = 16; multiple selections possible for Q10).

- **Mitigation strategy effectiveness and practical realism:**

Question 11 examined how effective different mitigation strategies are perceived to be in reducing supplier-related risk in aerospace. The results show that most listed strategies were considered at least moderately effective, but with clear differences in perceived strength. Strategic partnerships with key suppliers received the highest average score, followed by supplier diversification and contingency planning. Dual or multiple sourcing and digital monitoring or risk analytics were also rated highly. This indicates that respondents perceive supplier-risk mitigation as a combination of sourcing, relationship-based, planning-oriented, and data-supported measures.

Question 12 then asked which mitigation strategies are most realistic for aerospace organizations in practice. Here, the strongest selections were dual or multiple sourcing, supplier diversification, contingency planning, strategic partnerships, and buffer inventory. By contrast, regionalization or localization, digital monitoring tools, and additive manufacturing were selected much less often as realistic practical measures.

Table 4.7.

Q11 & Q12 – Mitigation Strategy Effectiveness and Practical Realism

Mitigation strategy:	Avg. effectiveness score:	Effective / very effective:	Realistic in practice:
Strategic Partnerships with Key Suppliers	4.13	12 / 15	6
Supplier Diversification	4.07	14 / 15	10

Contingency Planning	4.07	12 / 15	7
Dual / Multiple Sourcing	3.93	13 / 15	12
Digital Monitoring / Risk Analytics	3.93	13 / 15	1
Safety Stock / Buffer Inventory	3.73	11 / 15	5
Critical Spare-Parts Positioning	3.67	9 / 15	2
Improved Information Sharing / Visibility	3.67	11 / 15	n/a
Supplier Development	3.43	8 / 14	4
Regionalization / Localization	3.07	6 / 15	1
Additive Manufacturing for Selected Spare Parts	2.93	4 / 15	0
Other	n/a	n/a	0

Note. Source: Author's own table based on Q11 and Q12 of the empirical survey conducted for this dissertation (n = 14–16; Q11 scale: 1 = not effective, 5 = very effective; multiple selections possible for Q12).

The comparison shows an important difference between perceived effectiveness and practical realism. Digital monitoring, for example, was rated as effective, but was selected only once as a realistic strategy. A similar gap appears for regionalization or localization, which was perceived as moderately effective but rarely selected as immediately realistic. The results therefore suggest that aerospace organizations may prefer mitigation strategies that can be integrated into existing procurement and supplier-management structures, such as dual sourcing, supplier diversification, contingency planning, strategic partnerships, and buffer inventory. More structural or technology-dependent responses appear relevant, but less immediately realistic in practice.

- **Localization, regionalization, and strategic response logic:**

Questions 13 to 15 examined whether localization, regionalization, diversification, or dual sourcing are perceived as suitable strategic responses to supplier-related risk. This section is particularly important for the dissertation because it connects the empirical findings with the later development of the supplier-risk and strategic-response framework.

Table 4.8.

Q13 – Agreement with Localization Statements

Rank:	Statements:	Average Score:	Agree / Strongly agree:
1	Localization can reduce geopolitical exposure	4.27	13 / 15
2	Localization can reduce lead-time-related risk	4.07	14 / 15
3	Diversification is often more realistic than full localization	3.80	12 / 15
4	Localization can improve response speed in disruptions	3.73	10 / 15
5	Localization may increase cost or reduce economies of scale	3.73	11 / 15
6	Regionalization of MRO support or spare-parts capability can improve resilience even when production remains global	3.53	8 / 15
7	Localization can improve visibility and control	3.27	6 / 15
8	Localization is often limited by aerospace certification constraints	3.00	5 / 15

Note. Source: Author’s own table based on Q13 of the empirical survey conducted for this dissertation (n = 15; 1 = strongly disagree, 5 = strongly agree).

Table 4.9.

Localization Conditions and Strategic Response Preferences

Q14 – Cases where localization or regionalization is most justified:	Selections:
Highly critical components	10
Long-lead-time components	6
Spare parts with high downtime impact	6
Geopolitically exposed supply items	3
Repair capability near operational bases / MRO hubs	3
Single-source items	2

Rarely justified	0

Q15 – Better strategic response for most aerospace supply risks:	Selections:
Depends on item criticality and context	8
Supplier Diversification	5
Nearshoring / Regionalization	1
Dual Sourcing	1
Localization / Reshoring	0
Not sure	0

Note. Source: Author's own table based on Q14 and Q15 of the empirical survey conducted for this dissertation (n = 15; multiple selections possible for Q14).

The results suggest that localization is mainly relevant for reducing geopolitical exposure and lead-time risk, but not as a universal solution. Respondents also indicated that diversification is often more realistic than full localization, especially because cost, scale, and certification constraints can limit implementation.

Localization or regionalization appears most justified for highly critical components, long-lead-time items, and spare parts with high downtime impact. This supports a conditional response logic: the suitable strategy should depend on item criticality, disruption consequence, geopolitical exposure, and practical feasibility rather than on a general preference for localization.

- **Digital tools, current use, and adoption barriers:**

Questions 16 to 18 examined the perceived usefulness, current use, and adoption barriers of digital tools for resilience and supplier-risk management in aerospace. The results show that digital capabilities are generally perceived as useful, but their current implementation remains uneven. Predictive maintenance systems received the highest usefulness score, followed by real-time supply-chain visibility tools, blockchain or traceability systems, supplier performance analytics, and AI or ML-based forecasting and risk detection.

Table 4.10.

Q16 & Q17 – Digital Capability Usefulness and Current Use

Digital capability:	**Avg. usefulness score:**	**Useful / very useful:**	**Currently used:**
Predictive Maintenance Systems	4.07	12 / 15	8
Real-Time Supply Chain Visibility Tools	3.93	11 / 15	7
Blockchain / Traceability Systems	3.87	11 / 15	5
Supplier Performance Analytics	3.79	11 / 14	n/a
AI / ML Forecasting and Risk Detection	3.73	10 / 15	3
Additive Manufacturing / Digital Spare-Parts Strategies	3.47	7 / 15	2
Digital Twins / Scenario Modelling	3.33	6 / 15	0
None of the above	n/a	n/a	5

Note. Source: Author's own table based on Q16 and Q17 of the empirical survey conducted for this dissertation (n = 14–15; Q16 scale: 1 = not useful, 5 = very useful; multiple selections possible for Q17).

The current-use results show that predictive maintenance tools, visibility or data integration tools, and blockchain or traceability systems are the most frequently used digital capabilities. At the same time, five respondents selected "None of the above," which indicates that digital adoption is not consistent across the participating sample. Digital twins and additive manufacturing appear less established in the current-use results, despite being included as relevant future-oriented capabilities.

Table 4.11.

Q18 – Main Barriers to Wider Digital Adoption

Barrier:	**Selections:**
Cost	7
Data Quality	2

Cybersecurity Concerns	2
Skills / Expertise Shortage	2
Certification / Compliance Issues	1
Integration with Legacy Systems	1
Organizational Resistance	1

Note. Source: Author's own table based on Q18 of the empirical survey conducted for this dissertation (n = 16).

Cost was the most frequently selected barrier to wider digital adoption. Smaller groups also identified data quality, cybersecurity concerns, skills shortages, certification or compliance issues, legacy-system integration, and organizational resistance. Overall, the findings suggest that digital tools are relevant for resilience and supplier-risk management, but their practical role depends on implementation of feasibility. Digitalization should therefore be treated as a support layer within the later framework, not as a guaranteed solution to supplier risk.

- **Open-ended findings:**

Questions 19 and 20 provided respondents with the opportunity to add open-ended comments on supplier-risk management and on the decision between localization and diversification. Because the number of open responses was limited, the answers are not treated as a separate qualitative evidence base. Instead, they are used as supportive indications that help contextualize the closed-question results.

Table 4.12.

Thematic Summary of Open-Ended Responses

Risk mitigation	Respondents emphasized mitigation, better risk analysis, and reduction of supply chain disruption.
Supply chain reliability	Reliability appeared as a recurring concern, especially in relation to stable supply and strategic response choices.
Lead time	Lead time was mentioned as an important factor in supplier-risk and response decisions.

Dependency reduction	Several responses referred to dependency, dependency level, or the need to reduce dependence on vulnerable suppliers.
Visibility and digital support	Visibility and the use of AI were mentioned as relevant support mechanisms.
Critical parts and sourcing logic	Critical parts and multi-sourcing appeared as relevant considerations for supplier-risk response.
Cost and reliability	Cost was the most visible theme in the localization/diversification question, often connected with reliability and effectiveness.

Note. Source: Author's own table based on Q19 and Q20 of the empirical survey conducted for this dissertation; responses were thematically summarized.

The open-ended responses reinforce several themes already visible in the closed questions. Risk mitigation, supply chain reliability, lead-time reduction, dependency reduction, visibility, critical parts, and cost considerations appear as recurring practical concerns. In particular, the comments on localization and diversification suggest that strategic response decisions are strongly influenced by cost, reliability, effectiveness, dependency level, and risk exposure. Overall, the open responses support the same conditional logic identified in the previous sections: supplier-risk responses should not be selected as generic measures, but according to the specific risk profile, operational consequence, and feasibility conditions.

4.3. Summary of Empirical Findings

The empirical findings provide descriptive expert input into supplier risks, disruption exposure, assessment criteria, mitigation strategies, localization options, and digital tools in aerospace-related supply environments. Because the survey sample is limited, the results are not statistically representative, but they indicate relevant patterns for the later framework development.

The results show a multi-dimensional disruption environment, with geopolitical conflict, supplier capacity constraints, pandemic-related disruptions, logistics bottlenecks, and regulatory or certification constraints as important factors. Supplier vulnerability appears strongest around capacity risk, geopolitical or location risk, and single-source dependency.

The main consequences are production delay, cost increase, aircraft downtime or AOG risk, assembly interruption, and quality or compliance exposure.

The findings also suggest that supplier risk assessment should combine several criteria, especially delivery reliability, supplier lead time, availability of alternative suppliers, quality performance, component criticality, visibility, and spare-parts support capability. The most realistic mitigation responses are supplier diversification, dual or multiple sourcing, contingency planning, strategic partnerships, and buffer inventory. Localization and regionalization appear relevant only under specific conditions, while digital tools are useful but limited by practical adoption barriers.

5. Discussion and Framework Development

The previous chapter has shown that supplier risk in aerospace supply environments is not perceived as a single isolated problem, but as a combination of disruption exposure, supplier vulnerability, operational consequences, assessment criteria, strategic response options, and implementation constraints. This chapter therefore discusses the empirical findings in relation to the literature review and develops the proposed supplier-risk and strategic-response framework. The objective is not to repeat all survey results, but to interpret the strongest patterns and translate them into a structured decision logic for aerospace manufacturing and MRO-related supply environments.

The literature review showed that supplier risk, mitigation strategies, localization, MRO continuity, and digital transformation are already addressed as individual themes. However, the remaining gap is their limited integration into one aerospace-specific decision logic. Supplier assessment alone does not explain which response should follow from a specific risk profile, especially when the same supplier disruption may affect manufacturing continuity, MRO service continuity, or both. The empirical findings support this gap by showing which risks, criteria, and response options are perceived as most relevant in practice. Because the survey sample is limited, the findings cannot be treated as statistically representative for the aerospace industry as a whole. Their value lies instead in providing structured expert input for framework development.

5.1. Interpretation of the Main Empirical Findings

The first important discussion point concerns the dominant supplier-risk priorities. The empirical findings indicate that the most critical vulnerabilities are concentrated around capacity risk, geopolitical or location risk, and single-source dependency. This aligns with the literature review, which showed that aerospace supply chains are exposed to structural interdependence, limited substitutability, long lead times, and geographically distributed supplier networks. The most important consequence is that supplier risk should not be treated as a generic procurement issue. The survey results connect supplier disruption with production delay, cost increase, aircraft downtime or AOG risk, assembly interruption, and quality or compliance exposure. This supports a framework that begins with the supplier-risk profile and the expected consequence of disruption rather than with a pre-selected mitigation strategy.

A second discussion point concerns the assessment logic. The results show that supplier-risk assessment in aerospace requires a multi-criteria view. Delivery reliability, supplier lead time, availability of alternative suppliers, supplier quality performance, component criticality, visibility or data transparency, repair or spare-parts support capability, and certification or approval dependency all appear as relevant criteria. This confirms the literature-based argument that aerospace supplier assessment cannot be reduced to price, delivery performance, or general supplier scorecards alone. Instead, it must combine operational, supply-side, quality, certification, information, and MRO-related criteria. In this sense, the empirical results strengthen the need for a framework that connects assessment criteria directly to strategic response options.

A third important finding is the difference between perceived effectiveness and practical realism. Strategic partnerships, supplier diversification, contingency planning, dual or multiple sourcing, and digital monitoring were rated positively as mitigation strategies. However, the strategies considered most realistic in practice were mainly dual or multiple sourcing, supplier diversification, contingency planning, strategic partnerships, and buffer inventory. More structural or technology-dependent measures, such as regionalization or localization, digital monitoring tools, and additive manufacturing, were selected much less often as immediately realistic practical measures. This distinction is important because it prevents the framework from presenting advanced or structural responses as automatically feasible. Digital tools, additive manufacturing, and localization may strengthen resilience, but only where the required cost, capability, data quality, certification feasibility, and implementation effort are manageable.

The localization findings reinforce the same conditional logic. Respondents tended to agree that localization can reduce geopolitical exposure and lead-time-related risk, while also recognizing that diversification is often more realistic than full localization. Localization or regionalization was considered most justified for highly critical components, long-lead-time items, and spare parts with high downtime impact. Building on the research gap developed in the literature review, the framework therefore focuses on integrating supplier assessment, strategic response selection, localization or regionalization considerations, digital support mechanisms, and MRO-related continuity requirements into one decision logic. Consequently, the framework should not ask whether localization is generally better or worse than diversification. It should ask under which conditions localization, regionalization, diversification, dual sourcing, buffering, or digital support is the most appropriate response.

5.2. Development of the Supplier-Risk and Strategic-Response Framework

On the basis of the literature review and the empirical findings, the proposed framework is developed as a conditional decision-support structure. Its purpose is to connect supplier-risk assessment with strategic response selection. The framework should therefore not be understood as a general supplier scorecard or as a list of mitigation measures. Instead, it follows a sequence in which the supplier-risk profile is first identified, the operational consequence is then clarified, and the response is finally selected through a feasibility filter. This reflects the research gap identified in section 2.10, where the literature review concludes that supplier assessment, localization or regionalization, digital support, and MRO continuity are not absent from the literature, but remain insufficiently integrated into one aerospace-specific decision logic.

Table 5.1.

Supplier-Risk and Strategic-Response Framework

Framework step	Key question	Main inputs	Output
1. Supplier-Risk Profile	What type of supplier risk exists?	Criticality, lead time, capacity exposure, quality risk, certification dependency, location exposure, alternative suppliers, visibility, MRO relevance	Defined risk profile
2. Consequence Domain	What would be affected by disruption?	Manufacturing continuity, MRO service continuity, or both	Consequence category
3. Response Matching	Which mitigation response fits the risk?	Risk type and consequence type	Suitable response options
4. Feasibility Filter	Is the response realistic?	Cost, certification, capability, scale, approval, data availability, implementation effort	Feasible, conditional, or unsuitable response

5. Strategic Decision Output	What action should be taken?	Preferred response or response combination	Action package and review logic

Note. Source: Author's own framework based on the literature review and empirical findings of this dissertation.

The first step requires the organization to define the supplier-risk profile. This includes whether the supplier or item is capacity-constrained, difficult to substitute, long-lead-time dependent, geographically exposed, quality-critical, certification-dependent, or relevant for MRO service continuity. The second step clarifies the consequence domain. A supplier disruption that delays assembly or interrupts production planning requires a different response logic than a disruption that creates AOG risk, spare-parts shortage, or repair turnaround delay. This distinction is central because manufacturing risk is mainly linked to production continuity, program stability, and assembly flow, while MRO risk is more directly linked to aircraft availability, approved parts, repair capability, and service continuity.

The third step matches the assessed risk to a suitable response option. Within the proposed framework, capacity risk or single-source dependency affecting production continuity can be linked to responses such as dual sourcing, supplier diversification, supplier development, strategic partnerships, or buffer inventory. Geopolitical or location-related exposure can be connected to diversification, nearshoring, alternative logistics routes, or selective localization. Long-lead-time components can be assessed in relation to lead-time monitoring, critical inventory positioning, alternative suppliers, or regional sourcing. For spare parts with high downtime impact, the framework considers critical spare-parts positioning, repair-network evaluation, pooling, regional MRO capability, or predictive maintenance support. Quality and certification-related risks are linked to supplier quality monitoring, approved alternative sources, traceability, and certification feasibility review, while visibility-related risks are connected to supplier performance analytics, data integration, real-time monitoring, and digital risk analytics. However, these response options should not be understood as automatic solutions. Each option must pass the feasibility filter, including cost, certification requirements, internal capability, data availability, implementation effort, and business-case suitability.

The fourth step is the feasibility filter. This step is necessary because the survey results show that not every effective strategy is considered realistic in practice. A response may be theoretically useful but still unsuitable if certification approval is difficult, if capability does not exist in the region, if the cost increase is too high, or if implementation would require unrealistic organizational effort. The final output of the framework is therefore not one universal strategy, but an action package. This may include a combination of supplier monitoring, diversification, dual sourcing, buffer inventory, supplier development, regional repair capability, digital visibility tools, or selective localization, depending on the risk profile and feasibility conditions.

5.3. Framework Implications

The contribution of the framework is that it connects the main elements developed throughout the dissertation: supplier-risk assessment, operational consequence logic, mitigation strategy selection, localization and regionalization decisions, digital support mechanisms, and feasibility assessment. It is relevant for both aerospace manufacturing and MRO-related supply environments because it does not assume that all supplier disruptions create the same effects. Instead, it separates production continuity from MRO service continuity while still allowing combined responses where both domains are affected.

At the same time, the framework should be understood as a decision-support structure rather than as a fully validated industry model. The empirical findings are based on a limited sample and therefore support the framework through expert perceptions rather than statistical proof. Nevertheless, the results are useful because they indicate which supplier risks, assessment criteria, and strategic responses practitioners consider most relevant. The following conclusion can therefore return to the research question and summarize how aerospace organizations can use structured risk assessment, conditional response selection, and feasibility-based decision-making to strengthen the resilience of critical supply chains.

6. Conclusion and Recommendations

This dissertation has shown that supplier-risk management in aerospace manufacturing and MRO-related supply environments requires a structured and conditional decision logic rather than one universal mitigation strategy. Critical supply chains cannot be secured only through localization, digitalization, inventory buffers, or supplier diversification in isolation. Instead, supplier risk must first be assessed through a structured risk profile, including criticality, lead time, supplier capacity, substitutability, certification dependency, location exposure, visibility, and spare-parts or repair-network relevance. The appropriate response then depends on whether the disruption would mainly affect manufacturing continuity, MRO service continuity, or both. For this reason, the central conclusion of the dissertation is that resilience depends on connecting risk assessment, operational consequence, strategic response selection, and feasibility evaluation within one integrated decision process.

The literature review and empirical findings both support this conclusion. The literature showed that aerospace supply chains are structurally complex, globally distributed, highly regulated, and dependent on specialized suppliers, long lead times, and limited alternative sources. It also showed that manufacturing and MRO supply environments are connected but not identical: manufacturing disruptions mainly affect production continuity, assembly flow, and program stability, while MRO-related disruptions more directly affect aircraft availability, repair turnaround, spare-parts access, and service continuity. The survey results reinforced this logic by showing that supplier risk is perceived as a multi-dimensional issue. Capacity risk, geopolitical or location exposure, and single-source dependency were identified as major vulnerability areas, while the main consequences included production delay, cost increase, aircraft downtime or Aircraft-on-Ground risk, assembly interruption, and quality or compliance exposure.

The main contribution of this dissertation is therefore the proposed supplier-risk and strategic-response framework. Its value lies in translating supplier-risk assessment into conditional response logic. The framework does not treat supplier-risk assessment as an isolated scoring exercise, and it does not present mitigation strategies as a generic list of possible actions. Instead, it links the supplier-risk profile to the affected consequence domain, matches this with suitable response options, and then applies a feasibility filter. This is important because a strategy may be theoretically effective but still unrealistic if certification approval is difficult, regional capability is unavailable, implementation costs are too high, data quality is insufficient, or internal resources are limited. The framework therefore supports practical decision-making by showing when responses such as dual sourcing, supplier diversification, strategic partnerships, buffer inventory, regional support capability, digital monitoring, or selective localization may be appropriate.

Based on these findings, aerospace organizations should strengthen supplier-risk assessment through multi-criteria evaluation rather than relying only on cost, delivery performance, or general supplier scorecards. Supplier-risk assessment should include delivery reliability, lead time, alternative supplier availability, quality performance, component criticality, certification dependency, visibility, and repair or spare-parts support capability. Mitigation strategies should then be selected according to the specific risk profile and operational consequence. Dual or multiple sourcing, supplier diversification, contingency planning, strategic partnerships, and buffer inventory appear as realistic core responses. Localization or regionalization should be applied selectively, especially for highly critical components, long-lead-time items, geopolitically exposed supply items, or spare parts with high downtime impact. Digital tools, including supplier analytics, real-time visibility systems, predictive maintenance, traceability solutions, and additive manufacturing, should be treated as support mechanisms rather than automatic solutions. Their practical value depends on data quality, system integration, certification feasibility, internal capability, and business-case suitability.

The dissertation is also subject to limitations. The empirical part was based on 16 survey responses, which means that the findings provide useful expert perceptions but cannot be considered statistically representative for the aerospace industry as a whole. In addition, manufacturing and MRO-related perspectives may not have been equally represented in the sample. Future research could therefore validate the proposed framework through a larger expert survey, company-specific case studies, or separate applications in aircraft manufacturing and MRO environments. Further research could also examine how digital supplier-risk tools, regional MRO capability, and selective localization strategies perform when applied in real organizational decision processes. Overall, the dissertation shows that resilience in aerospace supply chains depends not on one dominant solution, but on the disciplined connection between risk assessment, operational consequence, feasible response selection, and continuous review.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this dissertation, the author used generative Artificial Intelligence and AI-assisted technologies, including ChatGPT, and Microsoft Editor, as supporting tools in the writing process. These tools were used to assist with the development of initial outlines, language refinement, structural suggestions, summarization of working materials, formulation support, and correction of grammar, coherence, and academic style.

The use of these tools did not replace the author's own academic judgement, research responsibility, or critical analysis. All AI-assisted outputs were reviewed, edited, verified, and adapted by the author before inclusion in the dissertation. The author remains fully responsible for the accuracy, originality, integrity, and validity of the final submitted work.

No AI-generated content, interpretation, citation, or analytical conclusion was included without independent review and verification by the author. All references, source-based statements, empirical findings, and conclusions are based on the author's own research process, the reviewed literature, the collected survey data, and properly cited sources.

This declaration is provided to ensure transparency regarding the use of generative AI and AI-assisted technologies during the preparation of the dissertation.

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IX. Appendices

1. Explanation of Key Words and Abbreviations

	Term:	Short explanation:
AC	Advisory Circular	A guidance document issued by the FAA to explain acceptable ways of complying with aviation regulations.
AIMS	Adaptive Inventory Management System	A flexible inventory management system designed to improve spare-parts planning, vendor monitoring, and availability of required items.
AM	Additive Manufacturing	A production method, often known as 3D printing, where parts are built layer by layer from digital design data.
AHP	Analytic Hierarchy Process	A multi-criteria decision-making method that compares alternatives by weighting criteria through pairwise comparison.
AI	Artificial Intelligence	AI refers to computer-based systems that perform tasks requiring human-like intelligence.
AI	AI-based demand forecasting	The use of artificial intelligence to estimate future demand patterns based on available data, trends, and historical behavior.
AI	AI-driven analytics	The use of artificial intelligence to analyze large data sets, identify patterns, detect risks, and support faster decision-making.
	Aircraft maintenance 4.0	The application of Industry 4.0 technologies, such as sensors, data analytics, digital platforms, and predictive tools, to aircraft maintenance.
AOG	Aircraft on Ground	A situation in which an aircraft cannot be released for operation because a required part, repair, or maintenance action is missing or incomplete.
ARJ21	Advanced Regional Jet / Comac C909	A Chinese regional jet aircraft originally known as ARJ21 and later marketed as the Comac C909.
	Arm’s-length approach	A traditional buyer–supplier relationship in which transactions are mainly cost-based and less integrated than strategic partnerships.
	Blockchain	A distributed digital ledger that records transactions in a secure, transparent, and difficult-to-alter way.

	Blockchain-based traceability	The use of blockchain technology to verify the origin, movement, authenticity, and status of parts or materials across the supply chain.
BMW	Bayerische Motoren Werke	A German automotive manufacturer; in English, the name means Bavarian Motor Works.
	Bullwhip effect	A supply chain phenomenon where small changes in customer demand become amplified as they move upstream through suppliers.
CX/ CPA	Cathay Pacific	A Hong Kong-based airline used in the dissertation as an example of aviation spare-parts and inventory management.
	Digital twins	Digital representations of physical assets, processes, or systems that allow organizations to monitor, analyze, and simulate real-world supply-chain or maintenance conditions.
	Downstream firms	Firms positioned closer to the final customer, final assembly, or end use of a product within a supply chain.
E2E	End to End	A complete view of a process or supply chain from the first input or supplier stage to the final customer or operational outcome.
FAA	Federal Aviation Administration	The United States aviation authority responsible for regulating civil aviation safety, certification, and operational standards.
FMEA	Failure Mode and Effects Analysis	A structured risk assessment method used to identify possible failures, evaluate their effects, and prioritize risks.
	Focal firm	The main company or organization being analyzed within a supply chain, often the central decision-maker or coordinating actor.
	Heavy maintenance	Extensive aircraft maintenance work, usually involving major inspections, structural checks, component removal, and longer aircraft downtime.
ICT	Information and Communication Technology	Digital and communication technologies used to collect, process, transmit, and manage information.
	Inventory buffering	The use of additional stock or safety inventory to reduce the impact of shortages, delivery delays, or demand uncertainty.
IoT	Internet of Things	The use of Internet of Things sensors and connected devices to monitor assets, parts, inventory, or conditions in real time.

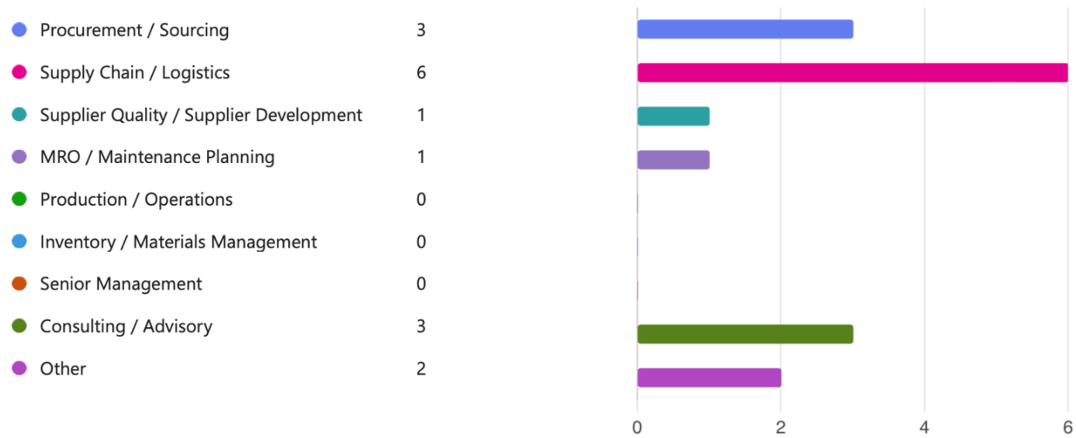
JIT	Just-in-Time	A lean supply-chain approach where materials or parts are delivered shortly before they are needed, reducing inventory but increasing exposure to disruption.
	Lean	A management and production approach focused on reducing waste, improving process flow, lowering unnecessary inventory, and increasing efficiency. In supply chains, lean structures can reduce cost, but they may also increase vulnerability when disruptions occur because fewer buffers are available.
LLM	Large Language Models	AI systems trained on large amounts of text that can understand and generate language, support queries, and assist with decision-related information retrieval.
	Lead time	The time required between placing an order or starting a process and receiving the required part, material, or output.
	Line maintenance	Routine aircraft maintenance performed during normal operations, often between flights or during short ground times.
	Localization	The placement of production, sourcing, repair, or support capability closer to the relevant market, production site, or operational region.
MADM	Multi-Attribute Decision Making	A decision-making approach used to evaluate alternatives based on several criteria or attributes.
	Maintenance 4.0	The use of digital technologies, data analytics, automation, and connected systems to improve maintenance planning, execution, and prediction.
MFT	Multi-Functional Teams	Teams composed of members from different functions, such as procurement, engineering, quality, logistics, or production, to support integrated decision-making.
ML	Machine Learning	ML is a branch of AI where systems learn patterns from data.
MRO	Maintenance, Repair, and Overhaul	Activities required to maintain, repair, inspect, overhaul, and return aircraft, components, or systems to serviceable condition.
NC	Numerical Control	The automated control of machining tools through programmed instructions, commonly used in manufacturing processes.
NDA	Non-Disclosure Agreement	A legal agreement that protects confidential information exchanged between parties.

	Nearshoring	The relocation of production, sourcing, or support activities to a geographically nearby country or region.
OEM	Original Equipment Manufacturer	The company that originally designs, produces, or supplies an aircraft, component, system, or part.
	Offshoring	The relocation of production, sourcing, or business activities to a foreign country, often to reduce cost or access specific capabilities.
	Occurrence (O), Severity (S), and Detection (D)	The three FMEA/RPN factors: occurrence estimates how likely a failure is, severity estimates its impact, and detection estimates how likely it is to be detected before causing harm.
PMA	Parts Manufacturer Approval	FAA approval allowing a manufacturer to produce replacement or modification parts for aircraft, engines, or components.
	Predictive Maintenance	A maintenance approach that uses data, sensors, and analytics to predict failures before they occur and plan maintenance more effectively.
R&D	Research and Development	Activities focused on developing new products, technologies, processes, or technical knowledge.
	Regionalization	The organization of production, supply, repair, or support capability within a specific region rather than through fully global supply structures.
RFI	Requests for Information	A procurement document used to collect general information from potential suppliers before a formal sourcing decision.
RFID	Radio-Frequency Identification	A technology that uses electronic tags and radio signals to identify, track, and monitor items.
RFP	Requests for Proposal	A procurement document asking suppliers to submit detailed commercial and technical offers for a product, service, or work package.
RFTI	Requests for Technical Information	A request used to collect technical information from suppliers, often before or during supplier evaluation.
	Reshoring	The relocation of previously offshored activities back to the firm’s home country.
	Risk exposure	The degree to which a firm, supplier, item, route, or process is vulnerable to being affected by a disruption.
RPN	Risk Priority Number	A numerical value used in FMEA, calculated from occurrence, severity, and detection, to prioritize risks.

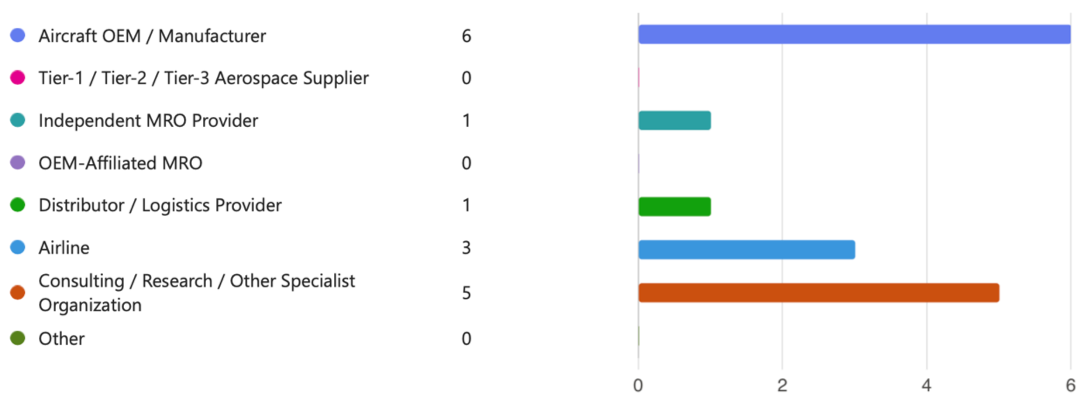
	Scenario modelling	The structured simulation of possible future situations, such as supplier disruption, transport delay, inventory shortage, or demand change, to evaluate potential response options.
SCM	Supply Chain Management	The planning and coordination of material, information, financial, supplier, production, logistics, and customer-related flows across a supply chain.
SCRM	Supply Chain Risk Management	The identification, assessment, mitigation, and monitoring of risks that may disrupt supply-chain performance.
SME	Small and Medium-sized Enterprise	A small or medium-sized company, typically with fewer resources and capacity than large corporations.
SWOT	Strengths, Weaknesses, Opportunities, and Threats	A strategic analysis tool used to assess internal strengths and weaknesses as well as external opportunities and threats.
	Upstream suppliers	Suppliers positioned earlier in the supply chain, often providing raw materials, parts, components, or subassemblies to later-stage firms.
	Visibility	The ability to observe and understand supply-chain status, including supplier performance, inventory, transport, part location, and disruption signals.

2. Survey Results

1. *Which of the following best describes your current role?*

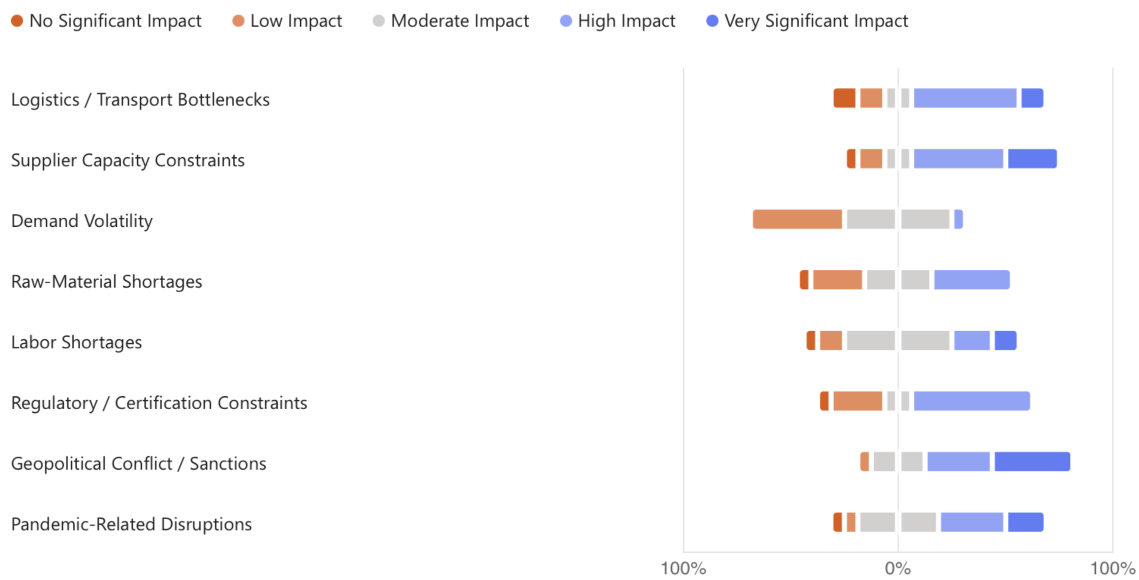


2. *Which type of organization do you primarily work in?*

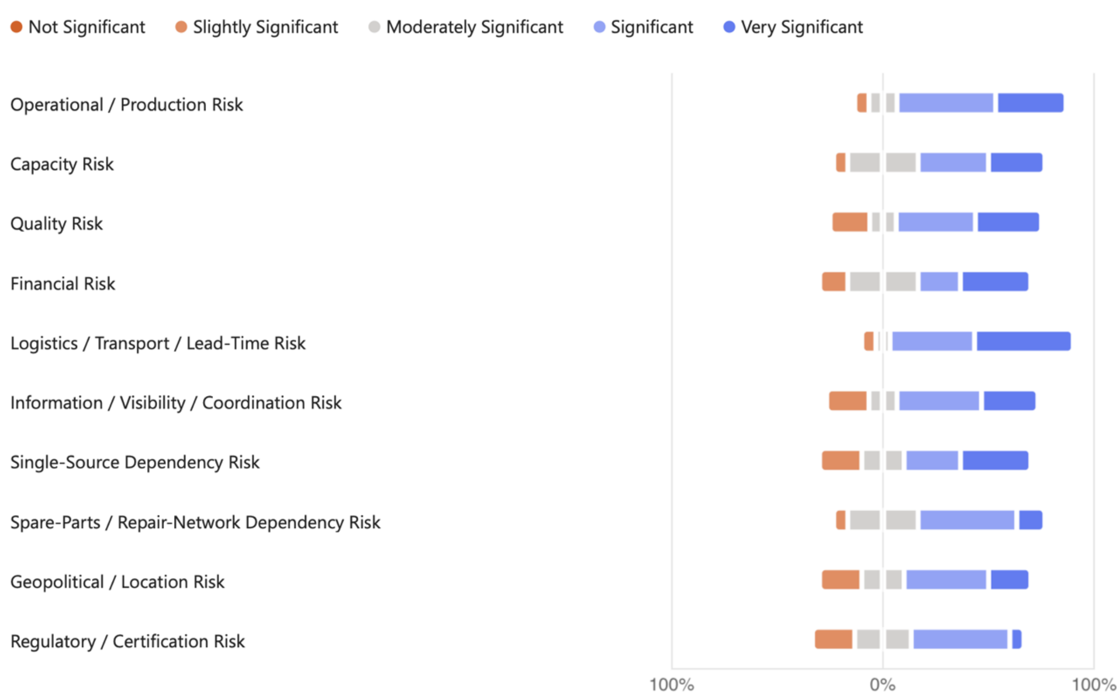


3. *Which supply environment is most relevant to your work?*

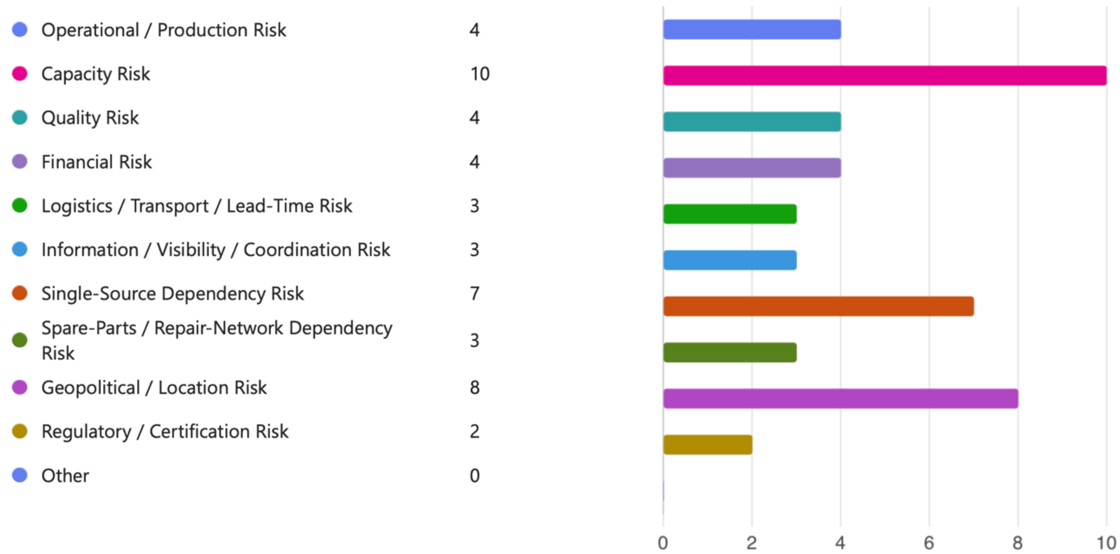
4. *How strongly have the following factors affected your supply environment during recent years?*



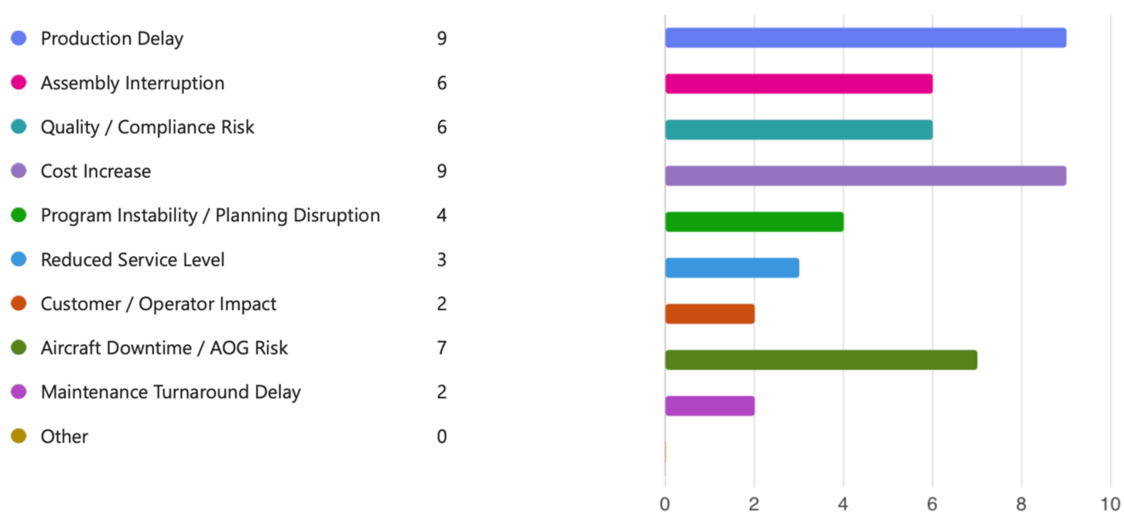
5. *In your view, how significant are the following supplier risk categories in aerospace supply chains?*



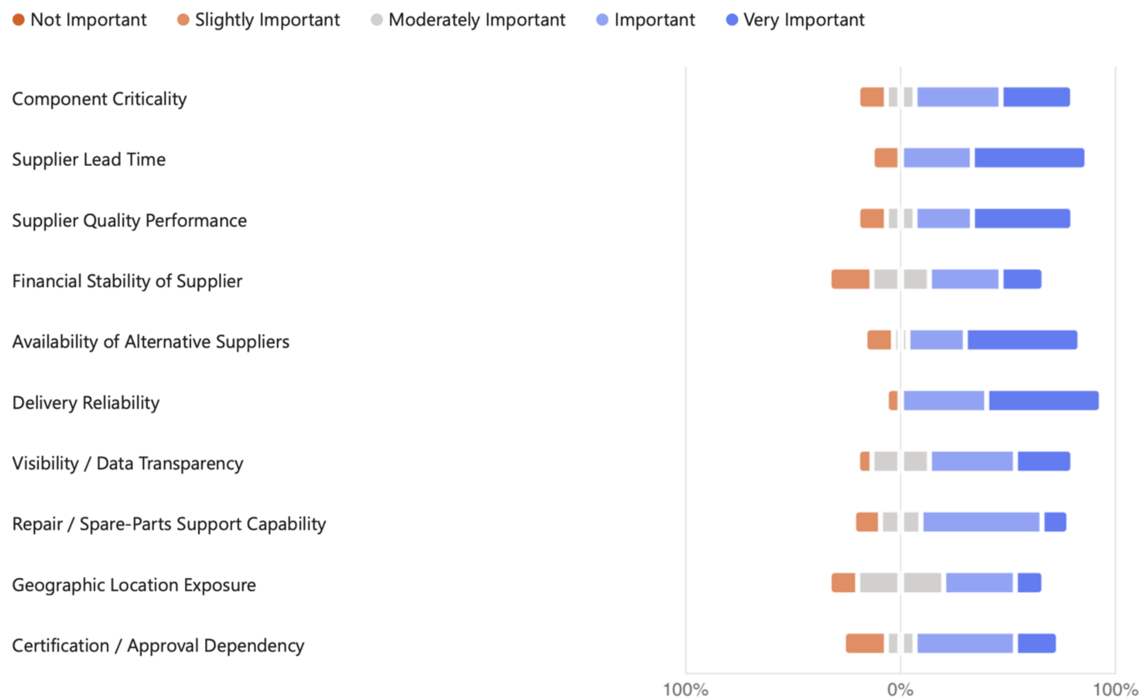
6. *Which three supplier risks currently create the greatest vulnerability in your organization or supply environment?*



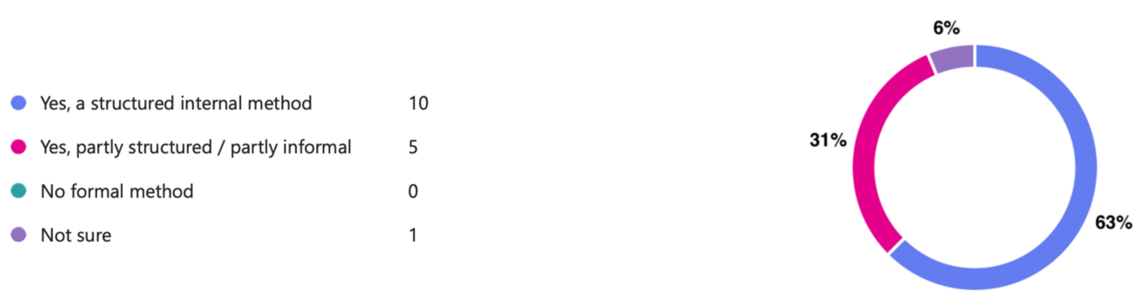
7. *Which of the following consequences are most critical when a key supplier is disrupted?*



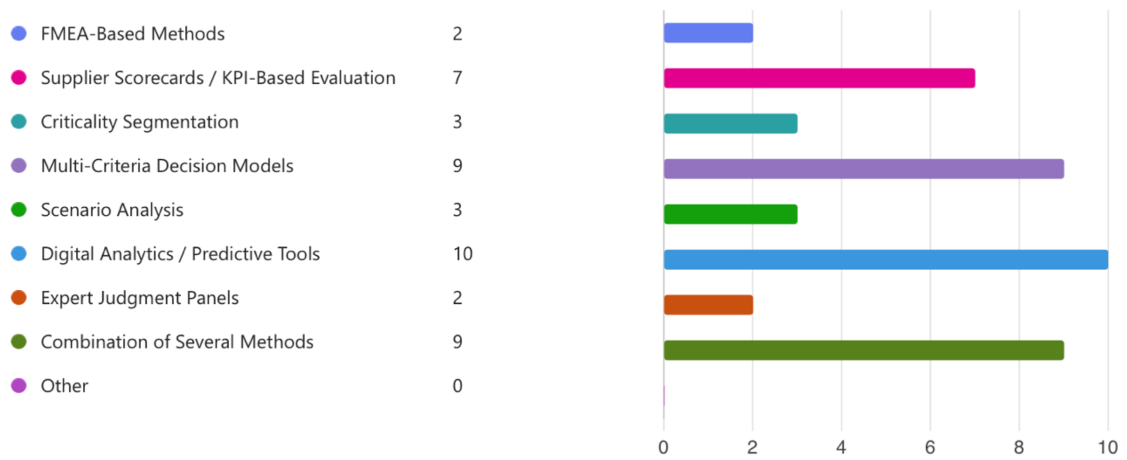
8. *How important are the following criteria when assessing supplier risk in aerospace?*



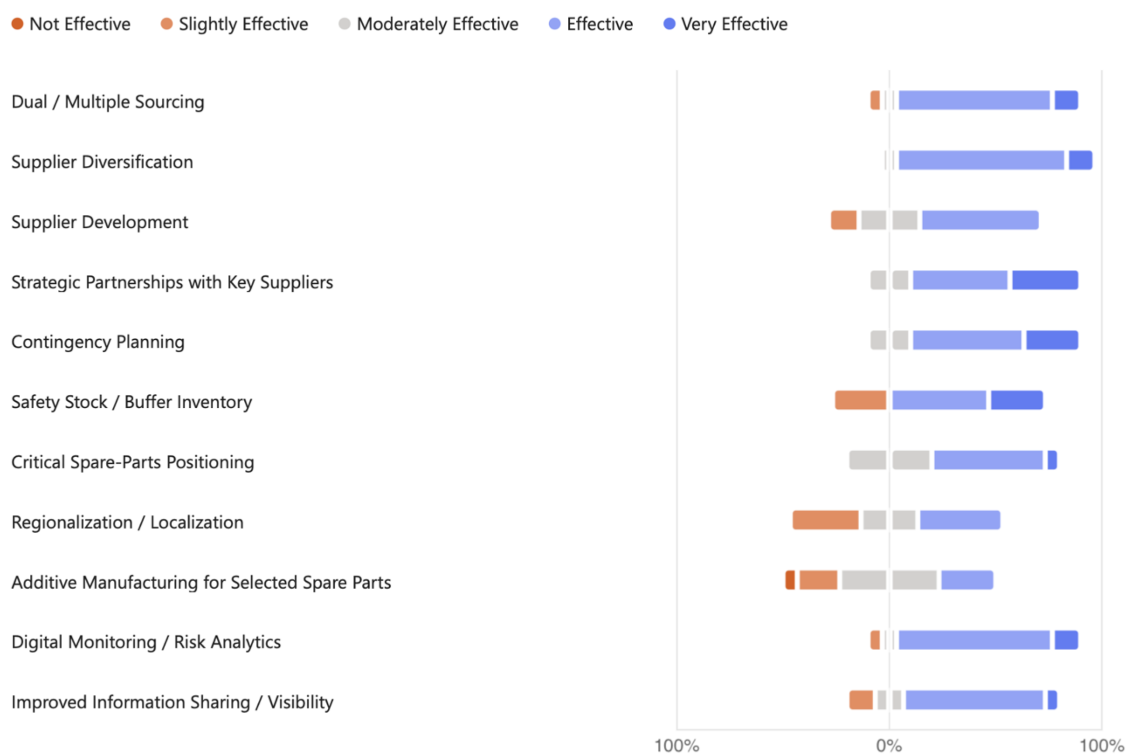
9. *Does your organization or supply environment use a formal method to assess supplier risk?*



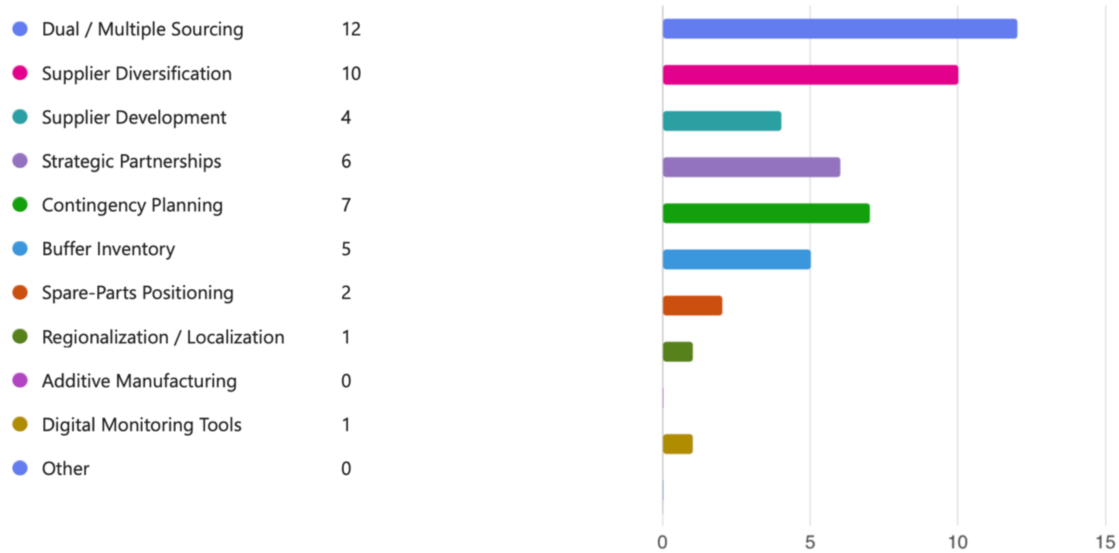
10. *Which approaches are most useful for supplier risk assessment in aerospace?*



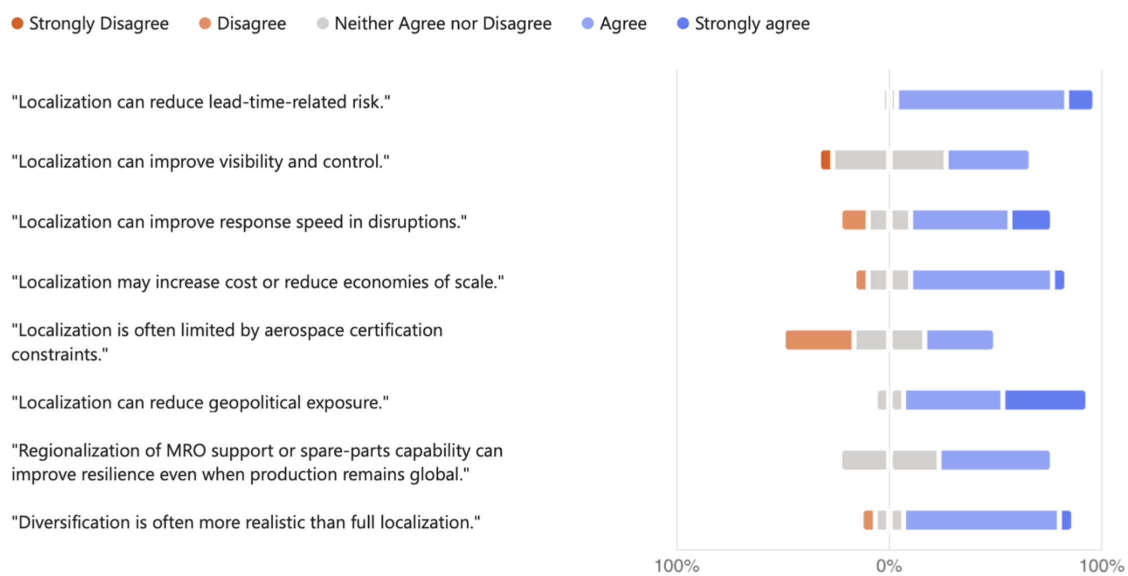
11. *How effective are the following strategies in reducing supplier-related risk in aerospace?*



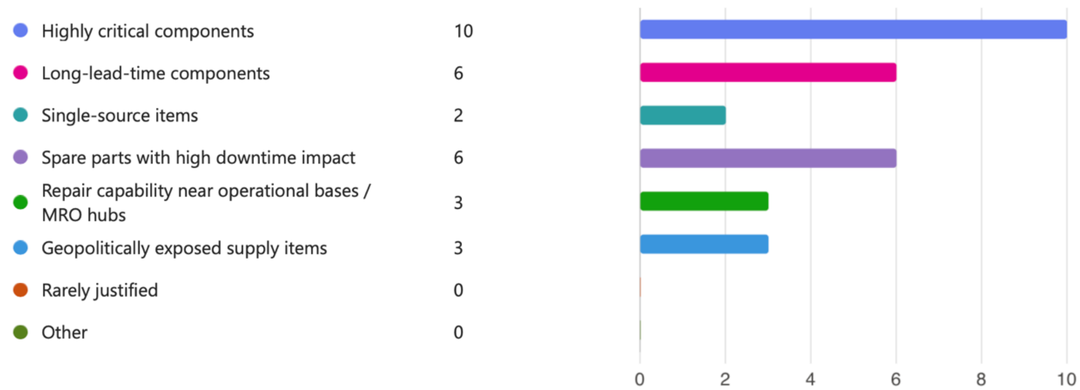
12. *Which mitigation strategies are the most realistic for aerospace organizations in practice?*



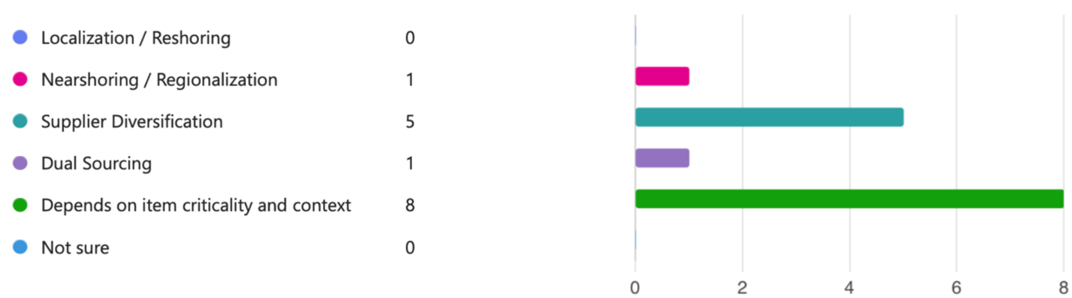
13. *To what extent do you agree with the following statements?*



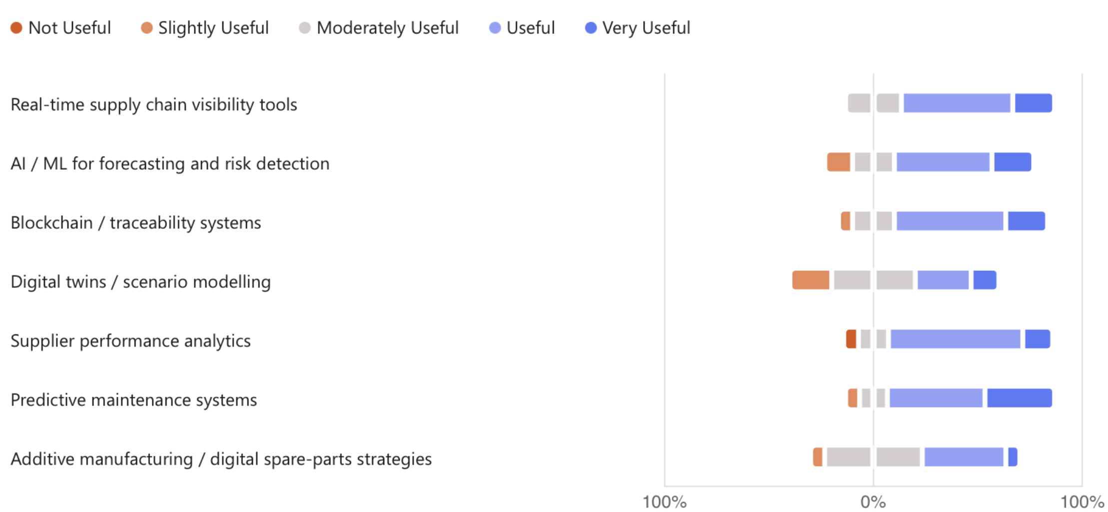
14. *In which cases is localization or regionalization most justified?*



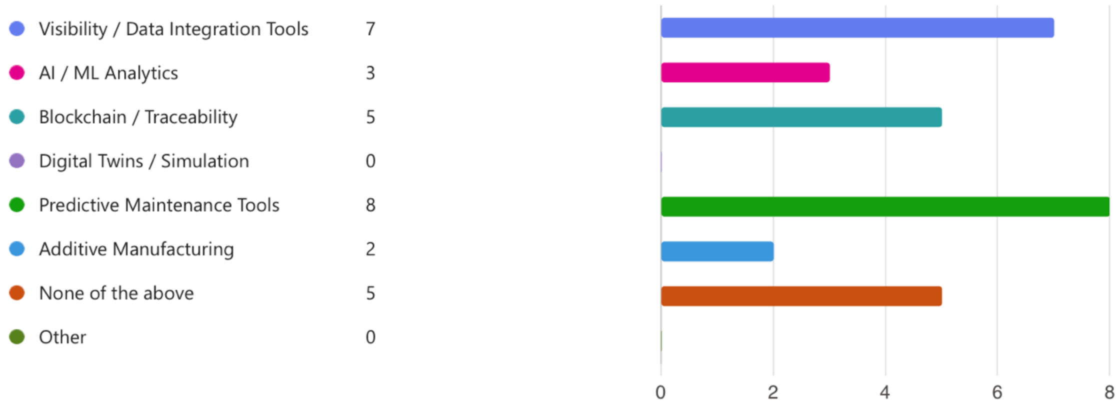
15. *Which is generally the better strategic response for most aerospace supply risks?*



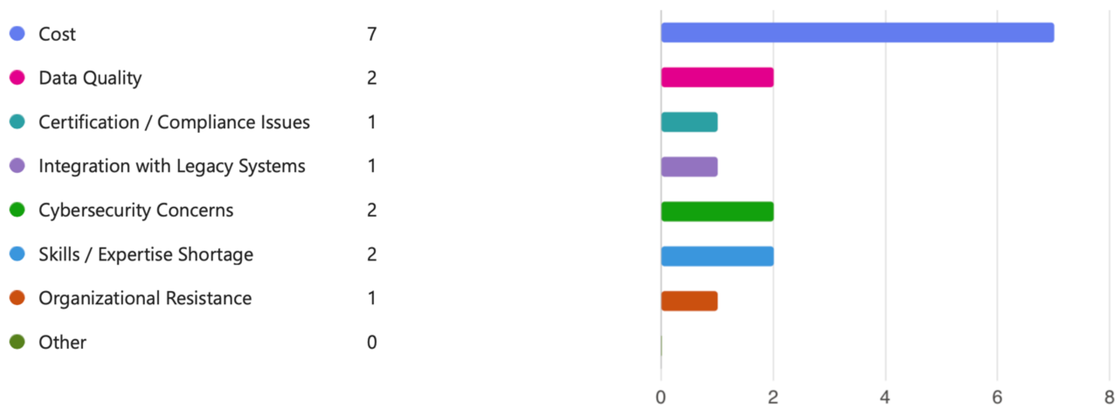
16. *How useful are the following digital capabilities for improving resilience and supplier-risk management in aerospace?*



17. *Which digital capability/tool is used in your company?*



18. *What is the main barrier to wider digital adoption in your environment?*



19. *In your view, what is the single most important improvement needed to strengthen aerospace supply chain resilience?*

11
Responses

Latest Responses
"Risk mitigation"
"Supply chain reliability"
...

20. *What is the single most important consideration when deciding between localization and diversification?*

10
Responses

Latest Responses
"Effectiveness"
"Costs"
...