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Article

Enhancing Supply Chain Efficiency in the Guangdong--Hong Kong--Macao Greater Bay Area's Air Transport System: A Perspective from Bullwhip Effect Mitigation

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Abstract: The Guangdong--Hong Kong--Macao Greater Bay Area (GBA) has developed a dense and functionally differentiated airport cluster that plays a critical role in regional and global logistics. However, its air transport supply chain still faces significant inefficiencies caused by fragmented cross-jurisdictional governance, long lead times, and weak information connectivity. These conditions intensify the bullwhip effect by amplifying demand fluctuations, distorting inventory decisions, raising logistics costs, and reducing supply chain responsiveness. Against this background, this study examines how the shared-airport model can improve supply chain efficiency from the perspective of bullwhip effect mitigation. Drawing on bullwhip effect theory and supply chain coordination theory, the paper argues that the shared-airport model reduces demand amplification through three main mechanisms: lead-time compression, information sharing with collaborative forecasting, and network optimization. Case evidence from the Dongguan--Hong Kong International Airport Logistics Park, Beijing Daxing Airport's shared equipment model, and the Qingdao Airport Super Cargo Terminal further demonstrates that institutional linkage, resource sharing, and front-end service extension can effectively reduce operational fragmentation and enhance logistics efficiency. Based on these findings, the paper proposes three strategic directions for the GBA: strengthening institutional coordination, building a regional digital logistics ecosystem, and developing a more resilient airport-network structure. The study concludes that the shared-airport model is an important pathway for mitigating the bullwhip effect and improving the efficiency, resilience, and integration of the GBA's air transport supply chain.

Keywords: greater bay area; air transport; bullwhip effect; shared airport; supply chain

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1. Introduction

The Guangdong--Hong Kong--Macao Greater Bay Area (GBA) has become one of the world's most important economic regions, supported by strong manufacturing capacity, intensive cross-border trade, and deep integration into global supply chains. In this context, air transport plays a vital role in ensuring the rapid circulation of high-value and time-sensitive goods. Recognizing this strategic importance, the Outline Development Plan for the Guangdong--Hong Kong--Macao Greater Bay Area explicitly emphasizes the construction of a world-class airport cluster and calls for stronger regional coordination in aviation and logistics. With major airports such as Hong Kong, Guangzhou, Shenzhen, Zhuhai, and Macao forming an increasingly connected airport network, the GBA has developed a solid foundation for becoming a leading international air transport hub. However, the region still faces major constraints in improving supply chain responsiveness [1]. Land scarcity in core hub cities, administrative fragmentation, and regulatory differences across jurisdictions continue to hinder resource integration and efficient cross-border cargo movement. These structural barriers have weakened the overall responsiveness of the GBA's air transport supply chain and limited its capacity to adapt to fluctuating market demand.

Such constraints are especially visible in traditional cross-border logistics operations, which often involve long procedures, repeated inspections, and insufficient information sharing among airports, customs authorities, freight forwarders, and shippers. Under these conditions, the bullwhip effect becomes a prominent challenge. As demand information moves upstream, small changes in final demand may be amplified into larger fluctuations in orders, inventory, and transport capacity. In the GBA's air transport supply chain, this effect is reflected in distorted demand signals, excessive safety stock, inventory backlogs or shortages, and rising logistics costs. Long lead times and low information transparency further intensify firms' reliance on conservative forecasting and batch ordering, thereby reducing supply chain efficiency and flexibility. Given the GBA's ambition to strengthen its role in global trade and logistics, mitigating these inefficiencies has become an urgent issue [2].

Against this background, this study explores how the shared-airport model can enhance supply chain efficiency in the GBA from the perspective of bullwhip effect mitigation [1]. It argues that closer inter-airport coordination, through mutual recognition of security procedures, direct data connectivity, and front-end cargo processing, can shorten lead times, improve information visibility, and reduce demand distortion across the supply chain. By clarifying these mechanisms, the paper seeks to explain how institutional and operational coordination can improve logistics performance in a cross-border airport cluster. The study contributes both theoretically and practically: it extends bullwhip effect analysis to the context of regional air transport coordination, and it offers useful insights for improving supply chain resilience, reducing logistics costs, and strengthening the GBA's competitiveness as a world-class aviation hub.

2. Theoretical Foundation and Literature Review

2.1. Bullwhip Effect Theory

The bullwhip effect is a key concept in supply chain management and an important framework for explaining inefficiency in air transport logistics. It is defined as the phenomenon whereby demand variability is amplified as information moves upstream from downstream markets to manufacturers and suppliers. In this process, small changes in final demand may generate much larger fluctuations in upstream orders, inventory, and capacity allocation. Although widely applied in manufacturing and retail studies, the concept has been less fully developed in cross-border air transport research [2]. This is particularly relevant to the GBA, where logistics operations are influenced not only by firm decisions but also by customs procedures, regulatory differences, and fragmented cross-border governance.

The literature identifies four major drivers of the bullwhip effect: demand forecast distortion, batch ordering, price fluctuations, and shortage gaming. Forecast distortion occurs when firms adjust expectations based on incomplete or delayed order information. Batch ordering amplifies volatility by replacing stable demand with irregular large-volume replenishment. Price fluctuations may encourage advance purchasing, while shortage gaming leads firms to inflate orders under uncertain supply conditions. These explanations remain useful, but they do not fully capture the GBA context. In the region's air transport supply chain, long lead times caused by customs clearance, security screening, and repeated cargo handling increase uncertainty, while fragmented data systems among mainland China, Hong Kong, and Macao weaken visibility of actual demand and cargo status. Therefore, extended lead times and cross-jurisdictional information silos should be treated as core structural causes of the bullwhip effect in the GBA.

Several methods have been proposed to quantify the bullwhip effect, including the variance ratio method, frequency response analysis, and the noise bandwidth approach [3]. Among them, the variance ratio method is the most widely used because it is simple and intuitive: when upstream order variance exceeds downstream demand variance, demand amplification exists. Frequency response analysis is more suitable for tracing dynamic fluctuations, while the noise bandwidth approach offers a more technical perspective on information distortion. However, both methods usually require more detailed time-series data and stronger modeling assumptions. For this study, the variance ratio method is more appropriate because it is practical, transparent, and better suited to the GBA context, where data consistency across jurisdictions remains limited.

2.2. Air Transport Supply Chain Coordination Theory

Supply chain coordination theory complements bullwhip effect theory by explaining how multiple actors can reduce inefficiency through closer collaboration. In general, it refers to the alignment of decisions, information, and resources among different participants in order to maximize overall rather than individual performance. In the air transport sector, this involves coordination among airports, airlines, freight forwarders, customs authorities, logistics firms, and shippers. Existing studies show that coordination can improve reliability, reduce duplication, and shorten lead times, yet much of the literature focuses mainly on inter-firm collaboration and pays less attention to institutional coordination across jurisdictions, which is especially important in the Greater Bay Area.

The key elements of coordination include information sharing, benefit allocation, trust mechanisms, and process integration. Information sharing improves demand visibility and reduces reliance on distorted order signals. Fair benefit allocation supports long-term cooperation, while trust reduces opportunistic behavior such as inflated ordering or information withholding. Process integration further improves efficiency by streamlining customs clearance, security screening, cargo handling, and inter-airport transfer procedures [3]. In the Greater Bay Area's air transport supply chain, these factors are not merely supportive conditions but essential mechanisms for mitigating the bullwhip effect. This is also why the shared-airport model is analytically important: it offers a practical path for shortening lead times, strengthening information sharing, and improving regional logistics efficiency.

3. Current State of the Bullwhip Effect in the GBA Air Transport Supply Chain

3.1. Overview of the GBA Air Transport Supply Chain

The air transport supply chain in the GBA is organized around a multi-airport system in which Hong Kong, Guangzhou, Shenzhen, Zhuhai, and Macao perform differentiated but interrelated roles. Hong Kong International Airport functions as the region's leading international cargo gateway with strong global connectivity and mature transshipment capacity. Guangzhou Baiyun International Airport serves as a major comprehensive hub linking domestic production bases with international routes, while Shenzhen Bao'an International Airport is closely associated with high-tech manufacturing, cross-border e-commerce, and express logistics. Zhuhai and Macao play more limited but potentially complementary roles in feeder transport, overflow handling, and future capacity sharing. Although this airport cluster provides a strong infrastructural foundation, its logistics performance remains constrained by incomplete coordination across airports and jurisdictions [4].

The supply chain involves manufacturers, airlines, airport operators, freight forwarders, logistics companies, and customs authorities. In theory, these actors should form a tightly connected system in which cargo demand, booking information, clearance status, and transport schedules are shared efficiently [5]. In practice, however, information often moves in sequence rather than in sync. Manufacturers depend on forwarders, forwarders rely on airport and customs processing, and airlines respond to booking signals that may already contain distortion. This weakens end-to-end visibility and makes the entire system sensitive to delay and misjudgment. A typical cargo movement still requires order confirmation, inland collection, consolidation, customs declaration, security screening, cargo storage, flight loading, and final overseas delivery. Once cross-border transfer is involved, repeated handling and fragmented verification often extend the process further, reducing responsiveness and increasing uncertainty. As shown in Figure 1, the GBA air transport supply chain is not only characterized by complex cargo flows across multiple nodes, but also by a sequential pattern of information transmission that creates favorable conditions for demand amplification.

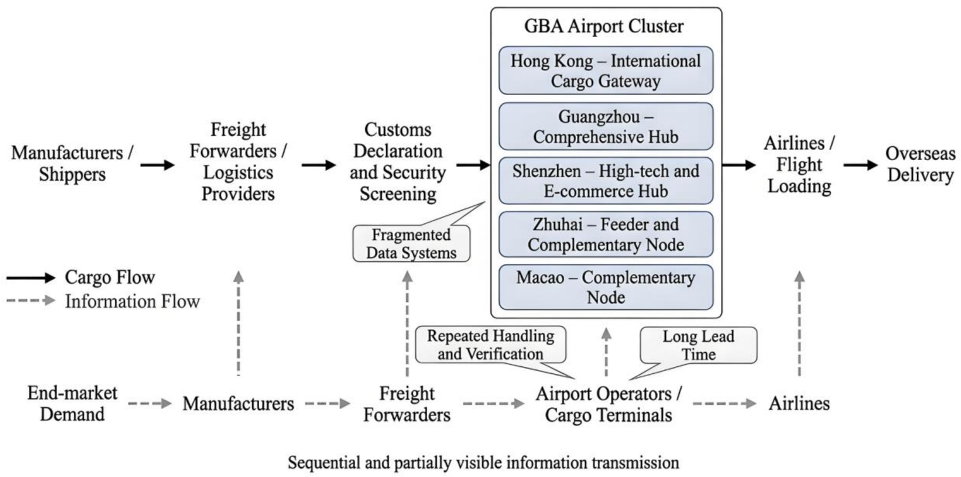

Figure 1. Cargo and Information Flows in the GBA Air Transport Supply Chain

3.2. Manifestations of the Bullwhip Effect

Under these conditions, the bullwhip effect becomes visible in several ways. Demand fluctuations at the market end are often magnified as they move upstream through freight forwarders, warehouse operators, and booking systems. Small changes in downstream demand may be interpreted as persistent growth or decline, leading upstream actors to over-adjust cargo allocation, flight booking, or warehousing plans. This mismatch contributes to unstable inventory decisions, particularly in sectors such as electronics and high-value manufacturing, where delivery speed and timing are crucial. Firms tend to maintain higher safety stock to hedge against lead-time uncertainty, but this often results in overstocking during weak demand periods and shortages during sudden surges [6].

The consequences are not limited to inventory. The bullwhip effect also raises transport, storage, and coordination costs. Excessive or precautionary bookings distort capacity planning, while longer pre-shipment waiting times increase warehousing expenses [7]. Management costs rise as firms repeatedly revise forecasts, reallocate cargo, and handle cross-border exceptions. More importantly, these distortions reduce supply chain responsiveness, weaken order fulfillment reliability, and undermine the speed advantage that air transport is supposed to provide.

3.3. Diagnosis of the Causes

The persistence of the bullwhip effect in the GBA can be attributed to three structural causes. The first is information fragmentation. Customs systems, airport platforms, and freight forwarding networks across mainland China, Hong Kong, and Macao are not yet fully interconnected. Consequently, upstream actors often rely on order data rather than actual end-market demand, increasing the risk of forecast distortion and amplifying temporary fluctuations [8].

The second cause is the combination of batch ordering and long lead times [9]. Due to the considerable fixed costs and procedural complexity associated with cross-border transport and clearance, firms tend to prefer larger and less frequent shipments. This ordering pattern exacerbates volatility even when actual demand changes only slightly.

Additionally, long lead times encourage higher safety stock levels, further reinforcing defensive ordering behavior.

The third cause is uneven regional coordination. Core hubs such as Guangzhou and Shenzhen face land and capacity constraints, while nearby cities with greater spatial potential, such as Zhuhai, have not yet been fully integrated into a coordinated cargo network. As a result, the GBA benefits from a strong airport base but lacks a sufficiently integrated logistics system capable of mitigating the bullwhip effect at the regional level.

4. Mechanism Analysis of the Shared-Airport Model in Mitigating the Bullwhip Effect

4.1. Connotation and Features of the Shared-Airport Model

The shared-airport model can be understood as an institutional and operational arrangement through which multiple airports within a regional aviation system achieve resource sharing, process coordination, and data interconnection. Rather than treating each airport as an isolated logistics node, this model integrates airports, cargo terminals, customs systems, and inland logistics facilities into a coordinated network [8]. In the GBA, this model is especially important because the airport cluster is marked by dense infrastructure, differentiated functions, and cross-jurisdictional governance. Under conventional arrangements, cargo processing is often fragmented across airports and regulatory systems, with each node operating according to its own procedures, information standards, and capacity constraints. The shared-airport model seeks to address this fragmentation through institutional openness and cross-border operational linkage.

Its significance lies in several core features. Mutual recognition of security screening and related regulatory outcomes reduces duplicated inspection and repeated cargo handling. Direct data connectivity enables cargo information, booking status, and clearance progress to be transmitted more efficiently across actors. Simplified procedures reduce operational handoff points, lowering the risk of delay and information distortion. Resource integration also allows the airport cluster to function as a coordinated logistics network rather than a collection of separate hubs. In this sense, the shared-airport model is not merely a technical adjustment, but a broader governance mechanism for improving regional logistics efficiency.

4.2. Mechanisms through Which the Shared-Airport Model Mitigates the Bullwhip Effect

The first mechanism is lead-time compression. Long lead times increase uncertainty because firms must make decisions before actual demand becomes clear. Under such conditions, manufacturers and intermediaries tend to rely on defensive forecasting, batch ordering, and high safety stock, all of which intensify the bullwhip effect [10]. The shared-airport model reduces this problem by moving key logistics procedures forward and cutting duplication across nodes. When export declaration, security screening, and related procedures can be completed at inland or auxiliary facilities before cargo reaches the departure airport, the interval between cargo preparation and shipment is significantly shortened. In practice, logistics time can fall to roughly 14 hours, while operating costs may decline by about 30 percent. This change matters not only because it speeds up transport, but also because it reduces uncertainty in replenishment decisions.

If the bullwhip effect is measured as the ratio between upstream order variance and downstream demand variance, then shorter lead time narrows the forecasting horizon and weakens the incentive for large precautionary orders [11]. More frequent and smaller replenishment becomes possible, bringing order fluctuations closer to real demand. The shared-airport model therefore mitigates demand amplification by reducing the lag between information, cargo movement, and response.

The second mechanism is information sharing combined with collaborative forecasting. In traditional cross-border air logistics, information is unevenly distributed across participants. Manufacturers know production schedules, freight forwarders manage bookings, customs authorities control clearance information, and airports monitor handling capacity, yet these data are not always synchronized in real time. As a result, supply chain actors often rely on order history or partial signals rather than final demand information, which encourages exaggerated responses to temporary fluctuations [12]. The shared-airport model provides the basis for a cross-regional digital platform linking manufacturers, forwarders, customs systems, and airport operators. With end-to-end visibility, cargo status can be tracked across the full process rather than inferred from isolated updates.

This improved visibility creates the conditions for collaborative planning, forecasting, and replenishment. As shown in Table 1, the shared-airport model differs from traditional airport logistics not only in speed, but also in information structure, decision logic, and capacity organization. These changes reduce forecast distortion, discourage panic ordering, and improve the consistency of operational responses.

Table 1. Analytical Comparison of Traditional Airport Operations and the Shared-Airport Model in Bullwhip Effect Mitigation

Analytical dimension	Traditional airport logistics model	Shared-airport model	Implication for bullwhip effect
Operational basis	Airport-specific procedures and fragmented processing	Cross-airport coordination and front-end processing	Less delay-induced uncertainty
Information structure	Sequential, node-based, and partially visible	Real-time, interconnected, and more transparent	Lower risk of signal distortion
Decision logic	Independent forecasting and defensive ordering	Collaborative forecasting and coordinated replenishment	Reduced amplification of temporary fluctuations
Capacity organization	Concentration in a few core hubs	Distributed use of auxiliary cargo stations and regional nodes	Less congestion-driven volatility
System resilience	Vulnerable to localized disruption	More flexible routing and processing alternatives	Greater stability in ordering behavior

The third mechanism is network optimization. A conventional airport-centered logistics system is vulnerable because cargo functions are concentrated in a few major hubs. Once congestion or procedural delay occurs at one of these hubs, disruption is quickly transmitted upstream, encouraging precautionary bookings and overstated orders. The shared-airport model reduces this vulnerability by shifting from a single-hub logic to a network logic based on a core airport plus auxiliary cargo stations. Under this structure, places such as Dongguan or Zhuhai can absorb part of the region's cargo consolidation, pre-processing, or feeder transport functions, thereby easing pressure on Hong Kong, Guangzhou, or Shenzhen. A more distributed logistics network also improves resilience by creating alternative routes and processing options [11]. As a result, local disruption is less likely to turn into system-wide order amplification.

4.3. Conditions for Effective Implementation

Despite its advantages, the shared-airport model cannot function effectively without supporting institutional and technological conditions. The first requirement is policy support, particularly mutual recognition of customs supervision, security inspection outcomes, and related regulatory procedures. Without such alignment, repeated checks and duplicated clearance will continue to erode the time-saving benefits of coordinated logistics. The second requirement is technological support. A shared-airport model depends on interoperable digital platforms capable of linking cargo information, customs data, booking systems, and handling schedules across jurisdictions. If data remain fragmented, the model may improve physical transfer efficiency without fundamentally changing the informational basis of supply chain decisions.

The third requirement is organizational coordination. Because this model involves airports, customs authorities, freight forwarders, logistics enterprises, and local governments, implementation requires a stable cross-regional coordination mechanism rather than temporary administrative cooperation [4]. Clear benefit-sharing arrangements, service standards, and dispute-resolution procedures are necessary to sustain long-term collaboration. Taken together, these conditions suggest that the shared-airport model should be understood not simply as a logistics innovation, but as a coordinated institutional framework. Its real significance lies in transforming a fragmented airport cluster into an integrated regional supply chain system capable of reducing uncertainty, stabilizing demand transmission, and improving overall efficiency.

5. Practical Cases of the Shared-Airport Model

5.1. Dongguan--Hong Kong International Airport Logistics Park

The Dongguan--Hong Kong International Airport Logistics Park is the most direct reference case for the Greater Bay Area (GBA). Developed by Airport Authority Hong Kong together with Dongguan partners, it functions as an off-site cargo processing extension of Hong Kong International Airport rather than a conventional inland warehouse. Its main significance is institutional: cargo can be processed in Dongguan while remaining connected to Hong Kong's international air-cargo system. In this sense, the project does not simply add storage capacity inland; it relocates selected airport functions outward and links them to an established global hub. This makes it a particularly relevant example for examining how cross-boundary coordination can reduce fragmentation in regional air logistics [13].

Its operational value lies in shifting key procedures forward. Export declaration, security screening, palletization, and airline-related processing can be completed before cargo reaches the departure airport, reducing repeated handling and shortening the interval between factory dispatch and uplift. Public reporting indicates that the project reduced logistics time to about 14 hours, lowered logistics costs by roughly 30 percent, and handled about 24,000 tons of cargo worth more than RMB 24 billion in its first two years. For this study, the case is important because shorter lead time and more predictable processing directly weaken the incentives for defensive ordering and excessive safety stock. It also shows that when firms can rely on faster and more transparent cargo processing, they are less likely to treat temporary uncertainty as a signal of future shortage. In other words, the project illustrates how procedural integration can indirectly stabilize ordering behavior.

5.2. Beijing Daxing Airport's Shared Non-Powered Equipment Model

Beijing Daxing Airport offers a different but analytically useful case. Its shared non-powered equipment model was introduced to address over-allocation, space waste, and management disorder in apron operations. Under traditional arrangements, individual service units tended to maintain their own equipment inventories, which increased idle assets, duplicated procurement, and weakened operational coordination. The shift to shared management therefore targeted a governance problem rather than a purely technical one.

The case is notable because sharing is applied to support resources rather than cargo itself. The airport first deployed 194 shared devices, planned more than 240 storage points, reduced space use by about 80 percent, and generated annual savings of roughly RMB 3 million. The model later improved winter service efficiency by cutting average towing time and raising work efficiency significantly. Its main lesson is that common standards, pooled resources, and centralized maintenance can reduce operational fragmentation, raise asset utilization, and improve service reliability [14]. For the Greater Bay Area, the implication is that the shared-airport model should not be limited to customs clearance or cargo transfer. It can also be extended to equipment, technical standards, and support services, thereby reducing uncertainty at the operational level before it appears as supply-chain volatility. This makes the Daxing case valuable as an example of how standardization and shared governance can strengthen the foundations of a more coordinated airport system.

5.3. Qingdao Airport Super Cargo Terminal

The Qingdao Airport Super Cargo Terminal provides a third perspective. Built with support from the free-trade-zone framework, it extends airport cargo functions closer to firms by moving key handling processes forward. Instead of waiting until cargo reaches the airport to begin core procedures, the model allows part of the handling chain to be completed earlier and closer to the source of production. This outward extension of airport services is especially important in regions where manufacturing activity is geographically dispersed and transport efficiency depends on closer linkage between industrial sites and airport operations.

The significance of the Qingdao case lies in service extension and institutional coordination. By combining front-end processing with customs facilitation and integrated transfer services, the model reduces logistics friction before cargo reaches the airport proper. This arrangement is particularly relevant to the GBA, where airport capacity is unevenly distributed and inland industrial clusters generate substantial export demand. For the GBA, the case suggests that shared-airport development should include not only airport-to-airport coordination, but also the outward extension of airport functions to bonded zones, inland consolidation centres, and manufacturing clusters. This reduces procedural delay, strengthens cargo visibility earlier in the chain, and improves the interface between production networks and air logistics. As a result, it offers a broader interpretation of "sharing" that includes service relocation as well as operational integration.

As Table 2 indicates, the three cases are useful not because they repeat one model, but because each addresses fragmentation at a different level: cross-boundary cargo processing, shared operational resources, and front-end service extension. Read together, they show that the shared-airport model is best understood as a family of coordination mechanisms rather than a single institutional template.

Table 2. Distinct Lessons from Three Shared-Logistics Cases

Case	Level of innovation	Main managerial lesson	Most relevant contribution to the GBA
Dongguan–Hong Kong Logistics Park	Cross-boundary cargo processing	Institutional linkage can move airport functions outside the airport	Best direct template for shared-airport cargo coordination
Beijing Daxing shared equipment model	Operational resource governance	Pooling resources under common standards improves efficiency and control	Useful for extending sharing to equipment and support systems

Qingdao Super Cargo Terminal	Airport function extension	Front-end processing can bring airport services closer to firms	Useful for linking airports with inland logistics and bonded zones

Taken together, the cases support one central conclusion: the shared-airport model is effective when it reduces fragmentation before cargo reaches the final airport node. The Dongguan--Hong Kong case shows the value of cross-boundary procedural integration; Daxing demonstrates the benefits of shared operational governance; and Qingdao highlights the importance of moving airport services closer to production and trade networks. For the GBA, the main lesson is that mitigating the bullwhip effect depends less on isolated capacity expansion than on coordinated systems that shorten lead times, standardize operations, and improve information visibility across the regional logistics chain [8]. More broadly, the three cases suggest that efficiency improvement is most sustainable when institutional coordination, operational redesign, and resource sharing advance together rather than separately.

6. Policy Recommendations for Improving Air Transport Supply Chain Efficiency in the GBA

To enhance the efficiency of the air transport supply chain in the GBA, policy design should emphasize three interconnected dimensions: institutional innovation, technological empowerment, and network optimization [10].

6.1. Institutional Innovation: Breaking Barriers and Strengthening Integrated Coordination

The Greater Bay Area (GBA) should enhance mutual recognition of security screening and regulatory outcomes across jurisdictions. This approach would enable cargo processed in one location to move more efficiently through the regional network, minimizing repeated inspections and procedural duplication. Expanding the scope of "single declaration, region-wide circulation" could further reduce lead times and operational uncertainty. Additionally, a unified aviation logistics standards system should be developed. Establishing common service standards, operating procedures, and data-interface rules would facilitate better process alignment among airports, customs authorities, airlines, and logistics enterprises. Without such standardization, even robust infrastructure cannot achieve optimal coordination. Strengthening existing cross-regional cooperation mechanisms is also essential [8]. Regularized communication and collaborative problem-solving among major airports, regulatory bodies, and logistics stakeholders would enable the airport cluster to operate as an integrated supply chain rather than as isolated systems.

6.2. Technological Empowerment: Building a Digital Logistics Ecosystem

A shared public information platform for GBA air logistics should be developed to support real-time collection, transmission, and exchange of cargo, booking, clearance, and capacity data. This approach would enhance transparency, reduce information asymmetry, and provide a stronger foundation for collaborative forecasting and replenishment. Simultaneously, advanced digital technologies should be more widely implemented. Internet of Things systems can facilitate full-process cargo tracking, big data analytics can optimize demand forecasting and inventory planning, and artificial intelligence can improve routing, congestion management, and capacity allocation. Collectively, these technologies can enhance operational visibility and decision-making quality. Blockchain should also be explored as a complementary tool for multi-party data sharing. By improving traceability and data credibility, it can mitigate risks such as information manipulation, coordination failures, and fraud in cross-jurisdictional logistics operations.

6.3. Network Optimization: Building a More Resilient Supply Chain Structure

The GBA should continue developing a networked pattern of "core airport plus auxiliary cargo stations." Under this model, pressure on major hubs such as Hong Kong, Guangzhou, and Shenzhen can be partially absorbed by complementary locations including Zhuhai and Foshan. This approach would ease congestion while improving flexibility in cargo processing and routing. Additionally, multimodal transport should be promoted by strengthening the links between air, sea, rail, and road systems. Expanding transport combinations would reduce dependence on a single channel and lower the risk of local disruptions escalating into broader supply chain instability. Furthermore, the region should support the growth of leading aviation logistics firms through strategic cooperation, consolidation, and capacity building. Stronger logistics enterprises can enhance resource integration, service standardization, and network coordination across the region. Collectively, these measures indicate that improving GBA air transport supply chain efficiency requires more than isolated infrastructure expansion [6]. It necessitates a coordinated regional strategy where institutional alignment, digital integration, and network resilience progress in unison.

7. Conclusion and Outlook

This study has examined the air transport supply chain of the GBA from the perspective of bullwhip effect mitigation. It finds that the GBA, despite its strong airport infrastructure and global logistics importance, still faces significant inefficiencies caused by long lead times, fragmented information systems, and uneven regional coordination. These conditions amplify demand fluctuations, distort inventory decisions, raise logistics costs, and weaken supply chain responsiveness. Against this background, the shared-airport model emerges as a promising solution. By shortening lead times, improving information visibility, promoting collaborative forecasting, and optimizing the regional airport network, it can reduce the structural drivers of the bullwhip effect and enhance overall supply chain efficiency. The case evidence further suggests that the model is valuable not only for cross-boundary cargo integration but also for resource sharing, process standardization, and service extension.

At the same time, this study has several limitations. Data availability remains a major constraint, especially in relation to cross-jurisdictional cargo flows, inventory dynamics, and real-time operational performance. As a result, the quantitative discussion in this paper remains relatively simplified and cannot fully capture the complexity of actual logistics behavior. In addition, some analytical assumptions regarding lead time, coordination efficiency, and demand transmission may differ from real-world conditions.

Future research can proceed in three directions. First, it can broaden the analytical scope by combining the shared-airport model with other supply chain optimization measures, such as multimodal transport coordination and platform-based logistics governance. Second, it can deepen quantitative analysis through more refined empirical data and more robust simulation or forecasting models. Third, more attention should be given to the role of emerging technologies and new governance arrangements in reshaping regional air logistics. Overall, the shared-airport model should be understood as an important pathway toward a more efficient, resilient, and integrated air transport supply chain in the GBA.

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