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Global Logistics Performance and Crisis Management: Evidence from COVID-19

Jiahui Xie^{1,†}, Kyeongsoo Kim^{2,†}, Su-Han Woo^{2,†}, Po-Lin Lai^{2,†} and Huay Ling Tay^{3,*}¹ Department of International Trade and Logistics, Graduated School, Chung-Ang University, Seoul 06974, Republic of Korea² Department of International Logistics, College of Business and Economics, Chung-Ang University, Seoul 06974, Republic of Korea³ Logistics & Supply Chain Management, School of Business, Singapore University of Social Sciences, Singapore 599494, Singapore* Correspondence: hltay@suss.edu.sg

† These authors contributed equally to this work.

How To Cite: Xie, J.; Kim, K.; Woo, S-H.; et al. Global Logistics Performance and Crisis Management: Evidence from COVID-19. *International Journal of Transportation and Logistics Research* 2026, 2(1), 4. <https://doi.org/10.53941/ijtlr.2026.100004>

Received: 14 March 2026

Revised: 21 April 2026

Accepted: 8 May 2026

Published: 15 May 2026

Abstract: Highly interconnected logistics systems facilitate the rapid flow of goods and humanitarian aid, but also shape the pathways through which health risks are transmitted during large-scale emergencies. While logistics performance is often considered to enhance crisis response capabilities, its impact on public health vulnerability during pandemics remains unclear. This study uses the COVID-19 pandemic as a starting point to explore the relationship between humanitarian logistics performance and pandemic severity and response capabilities in different countries. A three-stage analytical framework is employed: reviewing relevant theoretical and empirical research; utilising cross-national data and regression analysis to explore the link between pandemic transmission and logistics performance; and using Singapore as a case study to illustrate the regression results in logistics-intensive economies. The study reveals a paradox of logistics mobility and risk. While high logistics performance enhances responsiveness and system continuity, it may exacerbate public health risks by increasing interconnectivity and urban population concentration. Based on this, the study emphasises the importance of differentiated FDI governance, strengthened emergency planning, public health education, and the development of health-oriented smart logistics systems, redefining logistics performance as a determinant of health-related risks and resilience, and providing policy implications for improving preparedness for future public health crises.

Keywords: humanitarian logistics (HL); COVID-19 pandemic; supply chain management; urban mobility; public health

1. Introduction

Modern logistics systems are central to global trade and urban stability, and their dual role in responding to large-scale emergencies is becoming increasingly apparent. Whilst traditional logistics has been primarily driven by efficiency and cost control, public health crises such as the COVID-19 pandemic have overturned this logic, transforming logistics networks from economic enablers into channels for the transmission of systemic risk [1]. The 2022 lockdown in Shanghai serves as a prime example: whilst its automated ports, as a key Asian hub, remained operational, the labour-intensive last-mile delivery networks and distribution centres became critical nodes for virus transmission [2]. This not only led to regional supply chain disruptions but also revealed the link between the high-density movement of people and goods inherent in efficient logistics and public health vulnerabilities.



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From a broader perspective, influenced by war, disasters, pandemics, geopolitical conflicts and the climate crisis, the vulnerability of global logistics and supply chain systems continues to rise, with operational stability and the order of trade flows significantly weakened. Events such as the COVID-19 pandemic, the Israel-Palestine conflict and geopolitical tensions in the Middle East demonstrate that border controls, trade restrictions, infrastructure damage and labour shortages can rapidly trigger supply chain disruptions [3], leading to production stagnation, port congestion and rising transport costs, which pose a severe challenge to the long-term stability of global supply chains.

The cumulative transmission of multiple shocks across cross-border corridors and urban systems will further amplify the systemic vulnerabilities of logistics networks [1]. At the Asian level, the disruption of logistics channels between the mainland and Hong Kong during the pandemic fully illustrates this effect: as a global hub, Hong Kong relies heavily on integrated transshipment; the interruption of land transport not only triggered inflation but also hindered the circulation of medical supplies, directly threatening regional biosecurity [4]; The ‘Oxygen Express’ initiative in India in 2021 provides a complementary example: whilst it demonstrated logistics’ emergency support capabilities, the difficulties encountered in the emergency conversion of industrial facilities indicate that high network connectivity does not equate to crisis resilience [5].

The COVID-19 pandemic provides a unique and representative research context for this issue. On the one hand, during the pandemic, countries significantly weakened the cross-border flow of people and goods through border controls, travel restrictions, and lockdowns, bringing international transport networks to a standstill [6]. On the other hand, the data presents a seemingly contradictory phenomenon: many countries with highly developed logistics systems and strong international connectivity reported higher numbers of infections, yet their logistics systems and urban operations did not experience a corresponding degree of systemic collapse. This phenomenon raises a crucial question: does high logistics performance necessarily mean higher systemic risk, or earlier exposure and stronger response capabilities?

Existing research has yielded inconsistent conclusions regarding the relationship between the pandemic and logistics. Some studies argue that high globalization and logistical connectivity accelerated virus transmission, thus exacerbating the severity of the pandemic; others emphasize that logistical capabilities and institutional maturity contribute to enhancing system resilience and crisis response efficiency [7]. This divergence largely stems from different studies often treat logistical performance, economic openness, and institutional capacity as the same concept, neglecting the fact that they may function through different mechanisms during a crisis. Therefore, it is necessary to distinguish the different dimensions of logistics-related globalization at the macro level and systematically analyze their roles and pathways in the impact of the pandemic.

This research proposes that pandemic-related outcomes do not solely reflect the actual level of disease transmission, but are the result of multiple mechanisms working together. Therefore, this paper does not attempt to identify the causal effect of logistics performance on pandemic outcomes, but rather aims to explore, from a macro-comparative perspective, how different transportation and logistics-related dimensions shape the exposure paths and system response characteristics of pandemic shocks. This paper uses cross-national data to empirically analyze the association between logistics performance indicators and pandemic outcomes, controlling for national-level economic, urban structure, and international exposure characteristics. Simultaneously, using Singapore as a case study, it illustrates how a highly connected logistics system can mitigate the risk of systemic disruption under strong institutional coordination. Based on the above discussion, this paper proposes the following research questions:

RQ1: How do researchers study the impact of COVID-19? How does logistics affect COVID-19?

RQ2: Which factors can explain the heterogeneity exhibited by logistics systems under pandemic shocks?

RQ3: Why do macro-level empirical results sometimes contradict conclusions in existing logistics or public health literature, and how can these discrepancies be explained from a mechanistic perspective?

2. Literature Review

Previous research has confirmed that socio-economic factors and logistics conditions are key drivers of the spread of the pandemic [8]. International trade and economic interconnectivity have significantly altered the spatial transmission patterns of COVID-19 by intensifying cross-border flows of goods and people. Based on the above theoretical framework, this study selects six core indicators—urbanisation rate (URP), trade openness (TRO), foreign direct investment (FDI), value added in the logistics sector (LIVA), population density (PPD) and urban population size (UP)—to investigate the ‘mobility-risk paradox’ of highly interconnected logistics systems in relation to humanitarian aid, and the underlying causes thereof.

Empirical studies on the relationship between logistics and environmental performance often yield contradictory results. On the other hand, Karaduman et al., (2020) [9] showed that improvements in the logistics performance index (LPI) contribute to a reduction in carbon dioxide emissions per capita in a study of Balkan countries. The findings highlight the role of logistics efficiency in promoting environmental sustainability. On the contrary, examples from Asian economies suggest that the environmental benefits of logistics improvements can be offset by urban expansion and the intensification of industrial activities, potentially leading to increased CO₂ emissions despite improved logistics performance [10]. Given these contradictory results, further analyses of the interactions among logistics performance, urbanisation, and environmental pressures are needed.

The level of national income, as measured by GDP per capita, has historically been seen as an important factor in determining a country's capacity to respond to a public health crisis. The mainstream of existing research argues that rich countries are better prepared to mitigate pandemic-related mortality thanks to stronger healthcare systems, greater financial capacity, and superior crisis management capabilities [11,12]. However, empirical evidence alone cannot be considered a determining factor. For example, Wildman (2021) [13] conducted an empirical study using data showing that a significant number of high-income OECD countries have relatively high COVID-19 mortality rates compared with non-OECD countries. In other words, this suggests that factors such as an ageing population and the prevalence of chronic diseases may offset the benefits of economic prosperity.

Moreover, while FDI is widely recognised as a key driver of economic growth and structural change, it is also susceptible to uncertainty. Recent studies argue that pandemic-related uncertainty is a direct and clear cause of investment disruption. A study by Ho & Gan (2021) [14] found that the health pandemic had a statistically significant negative impact on net FDI inflows from 142 countries. These negative impacts were particularly noticeable in the Asia-Pacific region and emerging economies. This evidence distinguishes pandemic uncertainty from risks embedded in the broader economic and political landscape. This shows that the global health crisis can, in itself, weaken international investment flows.

Meanwhile, while TRO has traditionally been linked to economic efficiency and global integration, the COVID-19 pandemic has revealed a vulnerability to external shocks. Recent data suggest that the impact of TRO during a crisis depends heavily on the situation they are facing. Through compositional analysis, Mena et al., (2022) [15] demonstrated that trade resilience during the pandemic is more dependent on interactions with logistics performance, income levels, and institutional capacity than on trade openness itself. These findings suggest that while TRO may increase exposure to pandemic shocks, it may enable a faster recovery when supported by complementary state capabilities.

The number of COVID-19 cases has been widely used as a measure of the pandemic's severity. However, according to country-specific data, the prevalence of infection alone cannot fully explain the pandemic's mortality consequences. Pant et al. (2023) [16] have shown that there are significant differences in mortality even among countries with similar case numbers. They also highlighted the role of non-pharmaceutical and structural factors mediating the relationship between infection and death. Furthermore, their findings highlight that, beyond epidemiological exposure, government efficiency and logistics capacity play a decisive role in shaping mortality outcomes during the pandemic. Consistent with this view, COVID-19 mortality differed markedly even among countries experiencing similar levels of infection. Country-specific studies have shown that mortality is more closely associated with institutional capacity and logistical efficiency than with income levels or poverty indicators [16]. These findings suggest that pandemic mortality reflects the capacity of health crisis management systems rather than the number of confirmed cases. This highlights the importance of institutional preparedness and logistical coordination.

URP have traditionally been considered factors that exacerbate the spread of infectious diseases, as they are directly related to the frequency of human contact. In other words, these factors are recognised as a cause of the high frequency of human-to-human interaction. However, empirical evidence from the COVID-19 pandemic reveals more nuanced relationships. Hamidi et al., (2020) [17] analysed data collected from 913 metropolitan counties in the United States using structural equation modelling. The researchers found that population size and interpersonal contact were the main causes of infection rates, rather than PPD itself. In addition, after controlling for socioeconomic factors, PPD was negatively correlated with mortality.

UP reflects PPD and the scale of human interactions, and has long been associated with variations in health outcomes. McCulley et al. (2022) [18] conducted an exploratory study of 102 relevant studies. Based on their findings, they demonstrated that health outcomes do not scale linearly with city size but instead follow complex urban scaling patterns. The findings revealed that factors such as interpersonal connectivity, governance quality, healthcare capacity, and interaction affect health vulnerability. Conversely, the study suggests that UP itself has a low correlation with these results.

Finally, the relevant literature further indicates that the aforementioned drivers do not operate in isolation, but rather exhibit significant synergistic interactions. The combination of TRO and FDI with the intensity of LIVA can amplify the transmission effects of UR and PPD, thereby creating amplified pathways for viral spread within the trade–logistics–urban composite system; such multidimensional interactive effects are often overlooked in univariate analyze [8]. The correlation analysis framework adopted in this study effectively identifies the aforementioned synergistic mechanisms. This method not only examines the pairwise correlations between infection and mortality figures but also quantifies the comprehensive explanatory power of the indicator system, revealing deeper underlying driving patterns compared to univariate models.

3. Data and Methodology

This study utilises cross-sectional data from 155 countries spanning the years 2014 to 2023. The dataset divisions for the countries' names are detailed in the appendix. To capture a global snapshot of logistics performance and pandemic impact across multiple years, making cross-sectional data appropriate for identifying broad patterns. Time-series models were considered, but would require consistent annual LPI data, which was unavailable during pandemic disruptions. The COVID-19 cases (CC) and COVID-19 deaths (CD) data spanning the years 2020 to 2022 were obtained from the WHO (World Health Organisation). Although per capita measures are commonly used in cross-country pandemic studies to ensure comparability, this study adopts absolute CC and CD as the primary dependent variables. This choice is driven by the research focus on the total pressure exerted on logistics systems and national emergency response capacities. Moreover, population size effects are explicitly accounted for through the inclusion of PPD and UP as independent variables. In order to test the hypothesis raised in literature review section, we used the following model:

$$CC = \beta_0 + \beta X + \gamma Z + \varepsilon_0$$

$$CD = \alpha_0 + \alpha X + \delta Z + \varepsilon_1$$

where β_0 and α_0 is the constant term, X is the vector of independent variables (LPI, PPD, UP, URP, GDP, TRO, FDI, LIVA) and Z is the vector of control variables (geographic region). And ε is the error term. The data of LPI and the World Development Indicators, which were released by the World Bank in 2023 [19]. The impact of the pandemic transcends demographic and national boundaries, affecting individuals of all ages and nationalities with equal force and intensity.

OLS was selected for interpretability and simplicity in a global comparative context. While fixed or random effects could address heterogeneity, the primary goal was correlation analysis rather than causal inference. As Table 1 shows, robustness checks (VIF tests) were conducted to mitigate concerns about multicollinearity. VIF values for all explanatory variables are well below conventional cut-off levels (VIF < 10), indicating no serious multicollinearity issues.

Table 1. Result of the variance inflation factor test.

Variables	Dependent Variable: CC		Dependent Variable: CD	
	Model 1	Model 2	Model 1	Model 2
	Tolerance	VIF	Tolerance	VIF
FDI	0.955	1.047	0.955	1.047
URP	0.575	1.74	0.575	1.74
TRO	0.733	1.365	0.733	1.365
UP	0.587	1.703	0.587	1.703
PPD	0.785	1.274	0.785	1.274
LPI	0.093	5.938	0.093	5.938

The relationship between epidemics and world development indicators was then observed. Adjusted R-squared is a measurement of how well the independent variables in a regression model explain the variability in the dependent variable. From Table 2, more than 20% of the variance in the dependent variable is explained by the independent variables in the model; the CD proportion is much larger, more than 25%.

Table 2. Regression results.

Variables	Dependent Variable: CC		Dependent Variable: CD	
	Model 1 AdjR ² :0.204	DW = 2.136	Model 2 AdjR ² :0.257	DW = 2.163
	Coeffi	Sig.	Coeffi	Sig.
(Constant)	775,486.491	0.355	12,808.481	0.412
FDI	2.89×10^{-5}	0	4.36×10^{-7}	0
URP	-58,182.673	0.67	-801.517	0.753
TRO	-7596.391	0.024	-183×10^2	0.004
UP	9378.765	0.363	287.704	0.135
PPD	-117.321	0.658	-1.226	0.804
LPI	253.54	0.004	47.32	0.002

The descriptive statistics and correlation matrix in Table 3 illustrate the distribution and relationships between the variables. The overall LPI mean is 2.92, and the logistics performance of different regions can be assessed by comparing their values to this benchmark. The results indicate weak to moderate positive correlations between LPI and factors such as CC and CD, suggesting that countries with better logistics performance tend to experience relatively more severe epidemic situations. However, these relationships are not strong and should be interpreted with caution. This finding provides limited support for, and partly contrasts with, the conclusions of some previous studies [16,20].

Certainly, CD and CC are strongly related, and they show a negative correlation with TRO. It means that the more open a country's economy is to international trade and the more dependent it is on it, the less affected it is by the epidemic. On the other hand, a high number of infection-related deaths had a largely negative effect on exports and imports, aligning with the idea that balancing and reconciling health-related and economic outcomes is a challenging task [15]. However, FDI shows a positive correlation with both CC and CD, meaning that the greater the epidemic's impact, the more foreign investment is made within a country's borders. This intuitively contradicts previous research results indicating a negative correlation [14].

At the 0.05 significance level, CC shows a positive correlation with UP, suggesting that higher UP is associated with an increase in the number of infected cases. Similarly, URP is negatively correlated with the number of cases, implying that a higher proportion of urban population is associated with fewer infections. However, these two effects are not statistically significant in the regression analysis. Therefore, this relationship should be interpreted with caution. The correlation result may indicate a preliminary association, but it does not provide robust evidence of an independent effect when other variables are controlled for. These findings may tentatively suggest that urban population structure and density play a complex role in epidemic outcomes, potentially facilitating resource allocation and control measures while also posing risks under excessive density. This interpretation is broadly consistent with prior studies [17,21]. However, given the lack of statistical significance in the regression results, these explanations should be regarded as exploratory and warrant further investigation.

Table 3. Descriptive statistics and correlation matrix.

Description	LPI	CC (M)	CD (K)	TRO	UP	PPD	FDI (M)	URP	GDP	LIVA
Mean	2.923	1.551	19.19	89.257	60.747	251.299	11,252.09	1.907	2.658	26.861
Median	2.780	0.177	2.053	72.380	62.547	79.494	11,454.74	1.839	3.156	25.223
Std. Deviation	0.586	5.546	59.282	61.892	22.270	862.346	47,680.06	1.792	5.825	10.917
Minimum	1.716	0.227	-3.756	2.699	11.776	1.864	-330,338	-14.025	-32.909	2.759
Maximum	4.300	66.049	610.371	425.98	100.00	7918.95	49,308.00	12.771	63.368	70.549

Correlation Matrix										
LPI	1									
CC	0.263 **	1								
CD	0.182 *	0.729 **	1							
TRO	0.299 **	-0.115 *	-0.174 **	1						
UP	0.527 **	0.109 *	0.129 **	0.339 **	1					
PPD	0.238 **	-0.009	-0.023	0.567 **	0.202 **	1				
FDI	0.321 **	0.528 **	0.513 **	0.001	0.142 **	0.201 **	1			
URP	-0.392 **	-0.094 *	-0.095 *	-0.23 **	-0.451 **	-0.117 **	-0.118 **	1		
GDP	-0.106 *	0.053	0.041	0.061	-0.13 **	0.01	0.023	0.116 **	1	
LIVA	-0.088	-0.013	-0.041	-0.089 *	0.082 *	-0.15 **	-0.015	0.094 **	0.065	1

Note: The significance levels in this study are: white colour cells are values at $\rho < 0.1$, light blue shaded cells are values significant at $\rho < 0.05$ and dark blue shaded cells are values significant at $\rho < 0.01$.

Further investigate these relationships by dividing the world into five continents according to the World Health Organisation's classification. When comparing outcomes across countries of different population sizes in the case study section, proportional indicators are utilised to ensure fair comparison. Different continents have distinct epidemic prevention and control policies, and their development backgrounds also have their own characteristics. According to calculations, the global infection rate from 2020 to 2022 was 1.63%, with a subsequent 1.2% post-infection death rate. However, in 2023, considered the peak year for epidemic containment, the infection rate dropped to 0.57% while the death rate rose to 1.55%. Table 4 illustrates that Americas (AMRO) had a slightly higher CC than Europe (EURO), ranking first and second, respectively, but with a significantly higher Fatality Rate (FR). The COVID-19 pandemic outbreak, originating in Wuhan, China, in late 2019, spread rapidly worldwide. Initially, outbreaks tend to affect the originating country more severely due to factors such as delayed recognition and a lack of preparedness [22]. Notably, South-East Asia (SEARO) experienced more severe consequences compared to Western Pacific (WPRO), potentially influenced by factors such as resident adherence to Preventive Measures, Government policy [23], and Hofstede's Cultural Dimensions [24]. Efforts to minimize Fatality Rates are crucially tied to national initiatives [25]. Safeguarding the right to life and health is a fundamental responsibility [26]. Every state should do its utmost to protect the rights and interests of not only its citizens but also people around the world, which is also the pursuit of humanitarian logistics. The COVID-19 pandemic outbreak in 2020 disrupted the release of the Logistics Performance Index (LPI) report. While the LPI resumed in 2023, varying timelines for lifting epidemic restrictions globally led to a surge in cases and deaths [27]. The results showed a positive correlation, indicating that better logistics performance was associated with more infections, suggesting that logistics development did not meet humanitarian requirements. The drop in infection rates in 2023 confirmed the vaccine's effectiveness, while infection rates in WPRO also verified the importance of national policy and control.

Table 4. Comparison of data by continent (2020-2022).

	Mean 20-22 TTCC (M)	Mean 20-22 TTCD (K)	20-22 FR %	TP (M)	CC%	2023 TTCC (M)	2023 TTCD (K)	23 CC%	23 CASE%	23 LP
AFRO	22.040	379.920	1.72	7515.000	0.29	10.337	197.380	1.91	0.14	2.63
AMRO	217.872	3810.460	1.75	7267.283	3.00	73.951	1571.764	2.13	1.02	2.96
EMRO	27.276	457.981	1.68	7523.565	0.36	12.118	193.557	1.60	0.16	2.88
EURO	239.345	2219.888	0.93	7322.251	3.27	60.945	953.373	1.56	0.83	3.31
SEARO	72.582	984.988	1.36	6513.718	1.11	33.552	542.715	1.62	0.52	2.90
WPRO	128.752	308.845	0.24	7316.454	1.76	54.553	255.281	0.47	0.75	3.06

Note: Africa (AFRO), Americas (AMRO), Eastern Mediterranean (EMRO), Europe (EURO), South-East Asia (SEARO), and Western Pacific (WPRO), the regional divisions outlined by the World Health Organization.

4. Case Study

Singapore has long maintained a leading position in the global logistics arena, boasting well-developed infrastructure and an efficient operational system, a sound and rapid public health governance and early response mechanism, and its status as a regional logistics, pharmaceutical, and distribution hub [28]. As compared between Figures 1 and 2, in the face of COVID-19, despite its rapid initial spread, Singapore swiftly reduced its infection rate and achieved remarkable humanitarian success. Singapore's high-ranking logistics performance not only reflects its existing strengths but also demonstrates its crucial value as a regional logistics and pharmaceutical distribution centre during times of crisis.

Singapore boasts world-class port and airport infrastructure, and its highly automated customs clearance and cargo handling processes significantly enhance the overall efficiency of its logistics system [29]. These structural advantages serve as a major source of international competitiveness during normal times. However, in the early stages of the COVID-19 pandemic, they also created a highly mobile cross-border environment, thereby amplifying exposure risks through increased imported cases. Existing research indicates that developed economies with higher levels of FDI and denser international business and personnel exchanges tend to experience faster rates of virus importation and initial spread due to heightened human and business mobility [30]. As a regional logistics, pharmaceutical, and distribution hub, Singapore faced elevated risks of imported cases, aligning with the broader finding that high LPI countries often report higher infection rates in the early phases of a pandemic.

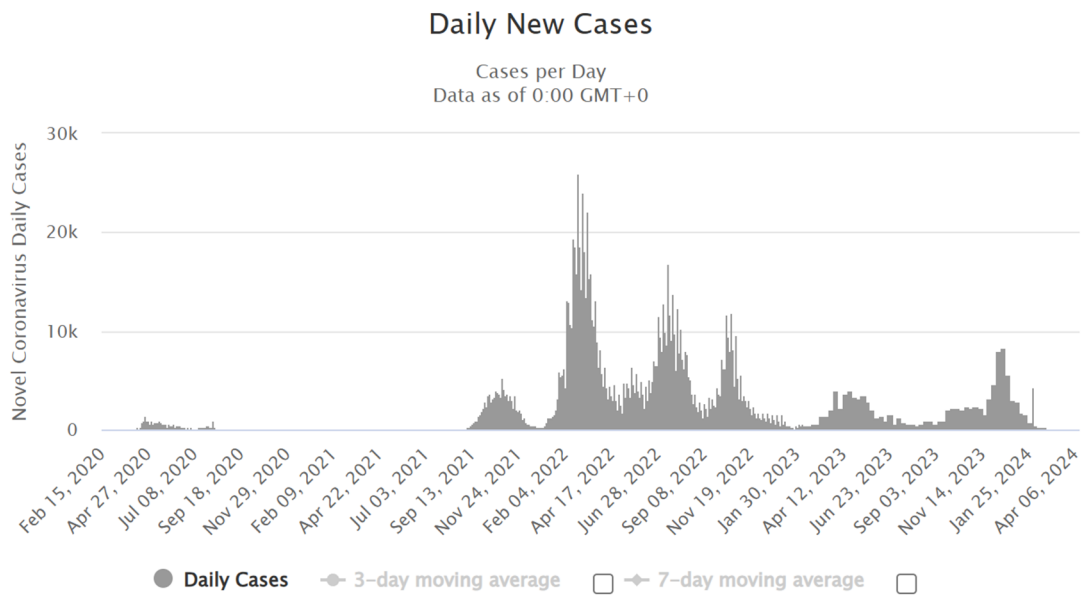


Figure 1. Singapore CC curve.

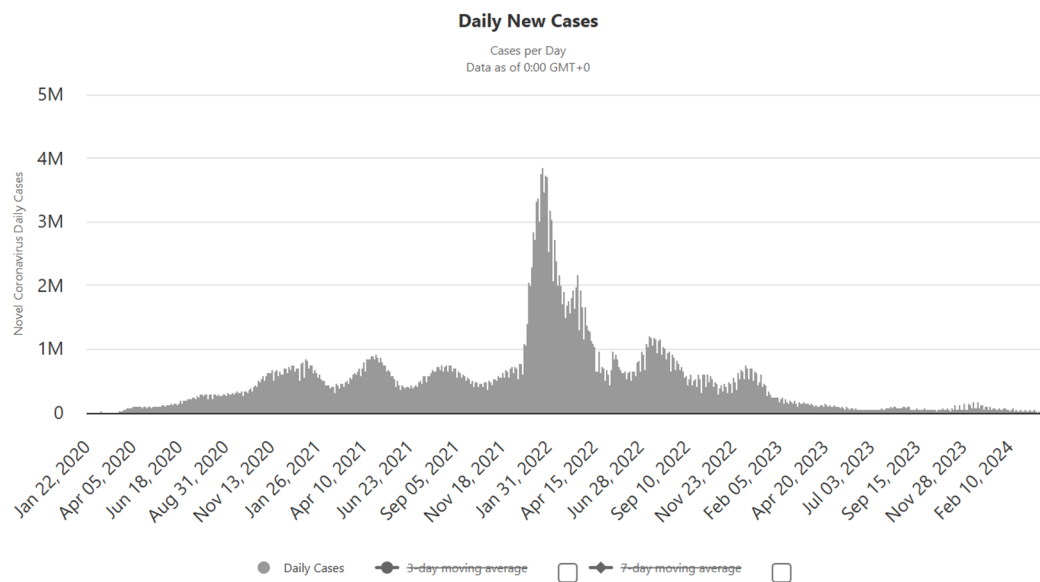


Figure 2. World CC curve. Source: WHO.

To counter these exposure risks while preserving logistics continuity, Singapore implemented decisive response measures. The “Circuit Breaker” lockdown imposed strict mobility restrictions on non-essential activities, effectively reducing domestic transmission channels without fully disrupting critical freight and supply chain operations [31]. Complementing this, the government rapidly deployed digital contact tracing tools such as TraceTogether and the SafeEntry system [32]. These technologies enabled swift identification and isolation of close contacts, thereby mitigating the virus’s spread within the highly interconnected urban-logistics system. This combination of measures illustrates the exposure–response duality: while superior logistics performance heightened initial vulnerability through global connectivity, it also provided efficient data systems, automated processes, and supply chain resilience that supported a rapid and targeted public health response.

Because the timing, location, and intensity of a disaster can only be determined after it occurs [33], and because excellent logistics infrastructure and services result from long-term efforts, the nature of humanitarian aid needs is highly uncertain. This success is largely attributed to Singapore's support for its emergency act plans. [34]. The circuit breaker implemented during COVID-19 was a powerful non-pharmaceutical intervention to reduce the frequency and density of contact, and its enforcement was supported by the Temporary Measures Act 2020 and related control order provisions [35]. This framework regulated patient and healthcare transfers, provided assistance to vulnerable groups to cope with the impact of the pandemic, and ensured the safe processing and

distribution of food [36]. On the one hand, logistics is a vector of epidemic transmission. on the other hand, it is a tool for delivering medical care and supplies.

On the one hand, logistics is a vector of epidemic transmission. On the other hand, it is a tool for delivering medical care and supplies. Singapore effectively leveraged this duality through several targeted measures. Although its highly urbanised and densely populated setting initially amplified exposure risks via intense international connectivity, the government activated the Public Health Preparedness Clinic (PHPC) network to decentralise testing, treatment, and vaccination services, thereby protecting hospital capacity [37]. At the same time, the Maritime and Port Authority and Civil Aviation Authority introduced “green channels” for essential medical and food cargoes, contactless cargo handling protocols, and “bubble-wrapped” cross-border driver arrangements with Malaysia. These measures minimised transmission risks while maintaining the uninterrupted flow of humanitarian aid and critical supplies. In addition, the Singapore Food Agency strengthened supply chain resilience through source diversification and strategic stockpiling [38]. Collectively, these policies illustrate that, under strong institutional governance, high-performance logistics systems can transform potential health vulnerabilities into effective response capacities, ensuring both supply chain continuity and public health protection.

In summary, Singapore is not an exception to the conclusion of global reversion; rather, it is an explanatory case revealing its internal mechanisms. In the early stages of the outbreak, high logistics efficiency, FDI, and a highly interconnected transportation network objectively made the logistics system a channel for risk transmission; however, in the governance phase, institutional capacity, public health coordination, and digital management transformed the same logistics system into a crucial support for humanitarian response and resilience building. This dynamic process demonstrates that the vulnerability and resilience of a logistics system can coexist within the same country, and its ultimate impact depends on governance methods and institutional arrangements, rather than the logistics capacity itself.

5. Conclusions

This study systematically examines the role of national logistics systems in shaping pandemic outcomes by combining macro-level empirical evidence with micro-level contextual interpretation. Using the number of infection cases and mortality rate as core indicators, the results show a significant association between logistics performance and COVID-19 pandemic outcomes [6]. By facilitating cross-border flows and accelerating the speed and scale of regional and international interactions, logistics systems may accelerate virus transmission in highly interconnected economies [39]. Therefore, higher logistics performance is often associated with higher infection and mortality rates [1]. This finding challenges the intuitive assumption that “stronger logistics capacity necessarily leads to more effective pandemic control.

The study further demonstrates that logistical capacity does not inherently possess positive or negative effects, but rather is a context-dependent mechanism, its effectiveness highly dependent on governance structures and the institutional environment. In the early stages of a pandemic, logistics may amplify liquidity risks as a transmission channel; however, in situations with effective public health governance capabilities, logistics can rapidly transform into critical infrastructure for humanitarian response. This conclusion aligns with existing literature, namely that in highly uncertain and resource-constrained environments, logistics plays an irreplaceable role in ensuring the continuous flow of medical supplies, food, and vaccines [15].

Regarding factors related to globalisation, the findings reveal significant heterogeneity. TRO is negatively correlated with the number of infection cases and mortality rates, indicating that, with adequate institutional support, integration into global trade networks helps countries maintain critical logistics flows during crises. Conversely, FDI is positively correlated with the number of infection cases and deaths, suggesting that international business flows may amplify exposure risks during outbreaks. This finding differs from some studies that emphasise how pandemic uncertainty suppresses investment, highlighting the need to distinguish between financial investment responses and real-world cross-border flow mechanisms [30].

The Singapore case study further reveals how outcomes in a single-country context can deviate from the global average and helps explain the mechanisms behind these differences. Singapore's advanced port and airport infrastructure, efficient global logistics network, and expedited customs clearance processes may have shortened the time lag between the global outbreak and virus importation, thus accelerating the initial spread of the pandemic. However, simultaneously, its strong public health governance capabilities enabled the logistics system to be rapidly transformed into humanitarian resources. Through digital contact tracing, coordinated supply chain management, and strict regulatory enforcement, Singapore effectively supported vulnerable groups while maintaining essential logistical functions. This case demonstrates that, in highly interconnected systems, logistic

vulnerability and resilience can coexist, and their ultimate impact depends on the effective integration of logistics with public health and governance systems.

From a policy perspective, the findings emphasise that logistics planning should be systematically integrated with public health and emergency governance frameworks rather than viewed solely as an infrastructure or efficiency issue. Policymakers could prepare for short-term crisis response measures, such as rapid activation of green logistics channels, prepositioned medical stockpiles, and contactless distribution networks [6]. While Long-term effort should be invested in logistics system design, including investments in diversified supply chains, cold-chain infrastructure, digital visibility platforms, and resilient urban–rural networks [40]. This dual approach can transform high-performance logistics systems from potential vectors of disease transmission into durable sources of national resilience during future public health emergencies.

This study also has certain limitations. First, cross-sectional data cannot depict the dynamic causal relationships at different stages of the crisis. Future research could employ panel data or time-series methods to analyse the evolution of logistics across the outbreak, spread, and recovery phases of the pandemic in greater detail. Second, while comprehensive indicators such as the Logistics Performance Index (LPI) are convenient for cross-border comparisons, they struggle to reflect differences at the operational level. Future research could incorporate micro-level enterprise data or real-time liquidity indicators to more deeply examine how logistics simultaneously influences the risk of pandemic transmission and the effectiveness of responses. Lastly, one potential limitation of this study is the use of absolute COVID-19 cases and deaths, which may be influenced by country population size. However, this approach is justified by the study's emphasis on total systemic impact and is mitigated by controlling for population-related variables and using normalized measures in comparative analyses. Future research could try per capita measurement.

Author Contributions

J.X.: data curation, methodology, software; K.K.: writing—original draft preparation; S-H.W.: visualization, investigation; P.-L.L.: supervision; H.L.T. : writing—conceptualization, reviewing and editing. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data will be made available on request.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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