Center for the Study of Western Hemispheric Trade
Texas A&M International University

WORKING PAPER SERIES
WP 2023-006
August 2023

# COVID-19 Effects on the Freight Transportation System in Mexico: A Demand and Supply Shock Analysis

**Miguel Gastón Cedillo-Campos**
**Carlos Daniel Martner-Peyrelongue**
**Alfonso Herrera-García**
**María Gabriela García-Ortega**
**José Elías Jiménez-Sánchez**
**Daniel Covarrubias**

freetrade.tamiu.edu

# COVID-19 Effects on the Freight Transportation System in Mexico: A Demand and Supply Shock Analysis

Miguel Gastón Cedillo-Campos[1]
Texas Center for Border Economic and Enterprise Development, Texas A&M International University, Laredo, Texas, USA

Carlos Daniel Martner-Peyrelongue
Instituto Mexicano del Transporte, Querétaro, Mexico

Alfonso Herrera-García
Instituto Mexicano del Transporte, Querétaro, Mexico

María Gabriela García-Ortega
Instituto Mexicano del Transporte, Querétaro, Mexico

José Elías Jiménez-Sánchez
Instituto Mexicano del Transporte, Querétaro, Mexico

Daniel Covarrubias
Texas Center for Border Economic and Enterprise Development, Texas A&M International University, Laredo, Texas, USA

*The COVID-19 pandemic continues to affect the transportation of goods worldwide. However, it is in emerging economies where its effects were the most adverse. While several studies currently seek to understand the levels of vulnerability and the impact on freight transportation during the pandemic, these works frequently assumed a developed markets context or a mono-transportation mode. Since the COVID-19 pandemic and the freight transportation system are transversal to national and global economies, it is necessary to have case studies that show both the demand and supply shocks and their effects in the different regions of the world. Based on a four-transportation mode perspective, this paper provides insights into the COVID-19 effects on the demand and supply sides of the freight transportation system in Mexico. It also proposes how "logistechs" (logistics technologies) can improve the efficiency and reliability of transportation networks, making them more resilient during supply chain disruptions such as the COVID-19 pandemic. Finally, this work provides public policy recommendations to mitigate the damages caused by the COVID-19 pandemic on transportation systems operating in emerging markets.*

*Keywords:* *COVID-19; transportation; logistics; resilience; supply chains; emerging markets, logistechs*

[1] Address correspondence to Dr. Miguel Gastón Cedillo-Campos, Texas A&M International University, Texas Center for Border Economic and Enterprise Development, 5201 University Boulevard, Laredo, Texas 78041. Email: dcova@tamiu.edu

## I. Introduction

The COVID-19 pandemic transformed how freight transportation should be organized. Resilience is now top of mind for public and private decision-makers. However, despite its global importance, there is a lack of case studies (by country and region) on how COVID-19 affects transportation performance as a system (four modes of transportation). The impacts of the pandemic have arisen at different levels and intensities in each transportation mode. Due to its importance in meeting the population's basic needs while maintaining its contribution to regional development (O'Rourke, Beshers, and Stock 2015; Savy 2017; Cedillo-Campos et al. 2019), transportation was considered by most countries as an "*essential activity.*" In Mexico, the Official Gazette of the Federation stated that transportation was an "*essential activity*" on April 8, 2020 (DOF 2020).

Since the number of future pandemics is likely to grow (WEF 2019; Whiting 2020), and because the COVID-19 pandemic has left clear evidence of the lack of global coordination (Blair 2020; Ng 2020), to extract lessons for the future, it is imperative that national case studies are developed today which will subsequently generate international comparative analysis.

The goal of this paper is twofold. First, to understand the impacts caused by COVID-19 on the demand and supply shocks of the freight transportation system in Mexico. Second, to have elements that will enable us to prepare the mechanisms of reaction, coordination, and execution of solutions from the perspective of sustainability and continuity of operations (COOP) when faced with the next global pandemic.

The COVID-19 pandemic continues to affect the transportation sector worldwide, mainly with more adverse effects on emerging economies. Although there are currently different studies that seek to understand the level of vulnerability and the impact on transportation during the pandemic, they mainly utilize the perspective of urban public passenger transportation operating in developed markets. However, since we are facing a global pandemic and freight transportation is transversal to national economies, having case studies that can be comparable would allow us a better understanding of the impact mechanisms and the solutions implemented around the world.

From this perspective, this paper contributes to the current body of knowledge by proposing a bi-dimensional analysis. Both the impacts from the demand and supply perspectives are analyzed in an integrated manner. Based on the case of Mexico, this paper provides information and analysis comparable to other countries regarding the implications of the COVID-19 pandemic for each of the four modes of transportation (maritime, air, rail, and road).

The rest of this article is organized as follows: Section 2 briefly states the supply chain context before the arrival of COVID-19 in Mexico. Section 3 describes the approach used for this analysis. Section 4 analyzes the demand and supply shocks for each mode of transportation. Section 5 presents practical conclusions useful for academics and decision-makers that include a brief discussion about the potential of "*logistechs*" (logistics technologies) (Covarrubias 2021) to enhance the resiliency of the Mexican freight transportation system; this section ends with a proposal for future research.

## II. Background

Global trade is currently bearing one of the most crucial transformation processes. Since the transformations generated by the terrorist attacks of September 11, 2001, in global supply chains, the terms "*reverse globalization*" or "*regionalization*" have become increasingly popular and

common worldwide. For the North American region, Cedillo-Campos, Sánchez, and Sharada (2012) analyzed the possible impacts of this new globalization status for Mexico and the USA. It was only until 2016, with Britain leaving the European Union (Brexit), that this trend gained global recognition.

During the last third of the 2010s, protectionist and even isolationist trends came up with greater force in some countries with significant weight in international trade flows (Martner 2020). This is the case of Brexit and the trade war between China and the United States (Khanna 2020), although dissatisfaction with the globalization process is more widespread and has given rise to various reactions and critical expressions (Dollfus 2007; Castells 2010; Crabtree 2020; Altman and Bastian 2021).

This creates structural changes in the design and operation of global supply chains. For example, in the case of Mexico, during the Donald Trump administration, the automotive industry operating in the North American region received pressure to relocate industrial production sites to the US. This is the emblematic case of the Ford Motor Company, which faced political pressure to stop the advanced work of installing a new assembly plant in San Luis Potosí, Mexico (Boudette 2017). However, recently, due to a different vision of regional competitiveness under the Joe Biden administration, the electric carmaker Tesla decided to build a new state-of-the-art factory in Monterrey, Mexico (Flores 2023).

Situations like the above, coupled with the economic difficulties already experienced in regions such as Latin America, led to a renewed interest in developing internal markets (Economist 2016; Capurro 2017; Shih 2020). Thus, while the economic world is divided into "*millions of markets*" (Caprice and Phadnis 2013) because of growing protectionism (Legrain 2020), consumer demands continue to increase. Consequently, supply chains reinforced their tendency to become increasingly vulnerable to variability (Cedillo-Campos et al. 2014).

Before COVID-19, the economy and world trade revealed a descending trend. A United Nations report (UN 2020) indicated that by 2019, the global economy registered its lowest growth in the entire decade, falling to 2.3% due to prolonged trade disputes and a slowdown in global investment. For its part, the Economic Commission for Latin America and the Caribbean (ECLAC), at the beginning of 2019, forecasted a 1.7% growth rate for this region. However, in December of the same year, it estimated the growth of Latin American GDP to be only 0.1% (ECLAC 2019).

In this sense, it is possible to state that the COVID-19 pandemic increased the previously prevailing trend in global economic performance. This revealed the state of strength in the productive structure of the countries. In the case of Latin America, it was already facing a long process of economic weakening. The health emergency induced severe damage by destabilizing supply and worsening demand capacity.

To be prepared for the next global pandemic, companies and governments are looking to use new technologies that could support the mechanisms of reaction, coordination, and execution of solutions from the perspective of sustainability and continuity of operations (COOP). It is under this context that logistics technologies (*logistechs*) could be useful. "*Logistechs*" is a concept that has emerged from Industry 4.0 and describes exponential technologies applied to improve the logistics, supply chain, and transportation sectors. Covarrubias (2021) classifies "*logistechs*" as exponential technologies that optimize the processes involved across the supply chain, from demand forecasting to route planning. The goal of implementing "*logistechs*" is to achieve greater efficiency and raise the level of customer satisfaction.

## III. Method

According to Savy (2016), the logistics analysis of the transportation system must consider the relationships between organizations as a system of flows (product flow, service flow, financial flow, and information flow) through which the supply chain effectiveness can be boosted. Supply chains form the "*structure*" of modern economies, using the various modes of transportation to generate "*logistics value*".[2] Consequently, the integral performance analysis of the four modes of transportation action is an essential element in improving the design of transportation policies that contribute to the effectiveness of national and global economies. Under this context, a demand and supply shock analysis based on a descriptive case study approach was applied.

However, the first problem that needed to be solved was data availability. Even assuming that the available data are accurate, they are insufficient and heterogeneous if one seeks to cover a broad international spectrum of analysis. There is no standardized method at a global scale to collect and deliver information on freight transportation. International organizations are not usually tasked with producing data; they collect data from national agencies and convert them into a standardized format. In this way, the nation-states set both the pace and quality of the available data (Savy 2017).

Faced with this critical challenge, this research work is based on the data sources available for each mode of transportation. This allows using descriptive statistics for the summary or description of the available data. In the case of maritime transportation, the information generated by the General Coordination of Maritime Ports and Merchant Marine of the Mexican Department of Communications and Transportation (SCT) was considered, as well as the database published by Sea Intelligence Consulting. In the case of rail transportation, two data sources were considered: i) monthly data aggregated at the national level and published by the Railway Transportation Regulatory Agency (ARTF), and ii) data published weekly by the American Association of Railroads (AAR). In the case of air transportation, the information generated by the Federal Civil Aviation Agency of the SCT was analyzed. In the case of road transportation, the databases originated at the General Directorate of Federal Motor Transportation of the SCT; additional data came from the study on the impact of COVID-19 on this mode of transportation carried out by García-Ortega and Jiménez-Sánchez (2021) and IMT (2020).

## IV. Analysis

### *Maritime transportation*

The most globalized mode of transportation is certainly the maritime one. More than 80% of international trade is moved by the global commercial shipping fleet. The most extensive supply chains (whether intercontinental or intra-continental) are linked to maritime-port logistics networks.

As a result, maritime cargo transportation is highly sensitive to elements such as: i) variations in the international economic environment, ii) policies that stimulate or inhibit trade, and iii) the specific logistics and economic dynamics of each country. In recent decades, due to climate

[2] According to Rutner and Langley (2000), the value of logistics is to enable organizations to meet customer service expectations in accordance with planning that simultaneously minimizes supply chain costs and maximizes benefits to all its participants.

change, another aspect that influences the fluctuations of maritime cargo flows is recurrent natural disasters. Earthquakes that lead to tsunamis, cyclones, and hurricanes are increasingly frequent and devastating, thus reducing or paralyzing maritime-port activity in focused points on the planet and for specific periods. However, unlike the above, the international expansion of COVID-19 had a much more powerful global impact than any other disruptive event experienced after World War II (Martner and Pérez 2020). Based on available data, the negative effects on the cargo movement through Mexican ports started in August 2019 (see Figure 1).

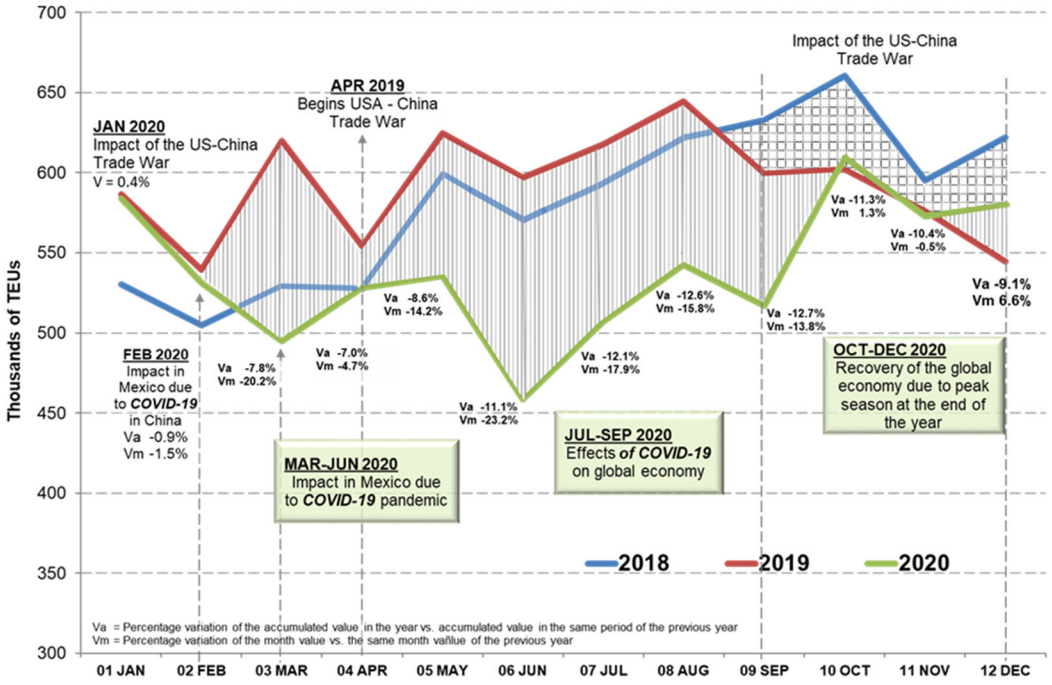


**Figure 1.** Monthly evolution of containerized cargo in Mexican ports, 2018 to 2020 (TEUs).

However, during January 2020, there was a slight rebound in flows, coming from the decreased international trade tension and the end of the USMCA (United States-Mexico-Canada Trade Agreement) negotiations. By February of the same year, the first effects of the closure of industrial production sites in China began to be felt due to the advance of COVID-19 in that country.

When analyzing the data of containerized cargo moved by Mexican seaports, growth remained at 8% (in twenty-foot equivalent units (TEUs)) during the first half of 2019. However, during the second half of that year, this impulse diluted until the end of the year with a slight increase of 1.7%.

*Demand shocks on maritime transportation*

In addition to the depressive economic environment generated by the new wave of protectionist policies and the trade war between the US and China, the progressive global expansion of COVID-19 during the first quarter of 2020 resulted in a demand shock on maritime transportation.

The economic effects of this pandemic were progressively staggered as COVID-19 advanced over the different regions and continents (Crotti, Ferrari, and Tei 2022). First, the productive

activities in Asia were paralyzed while factories remained open in America and the rest of the world; however, they could not be supplied with inputs from the Asian continent. It configured a "*reverse bullwhip effect*" (Cedillo-Campos et al. 2014; Bueno-Solano and Cedillo-Campos 2014), which caused increased costs and progressive disruptions of globalized supply chains. Europe closed its productive activities, and near the end of March 2020, confinement began in the North American region.

On the contrary, by the end of March 2020, Asian countries (especially China) began to reopen their productive activities, while the rest of the world entered rigorous confinement to contain the pandemic. Only the so-called "*essential activities*" remained open, that is, those related to the supply of health, food, and energy services. Such imbalances interrupted the normal cycles of the supply of goods and intermediate inputs, altering inventories and thus configuring a variant of the bullwhip effect known as the "*umbrella effect*" (Cedillo-Campos et al. 2014; Bueno-Solano and Cedillo-Campos 2014). That is, for example, when a large number of goods were "*trapped*" between the port of departure and the port of arrival.

From March to June 2020, there was a notable decrease in the cargo volume mobilized by international maritime transportation, which added limitations and restrictions on port operations in many countries. This evidenced the fragility of supply chains articulated by Mexican maritime-ports (see Figure 2 and Figure 3).

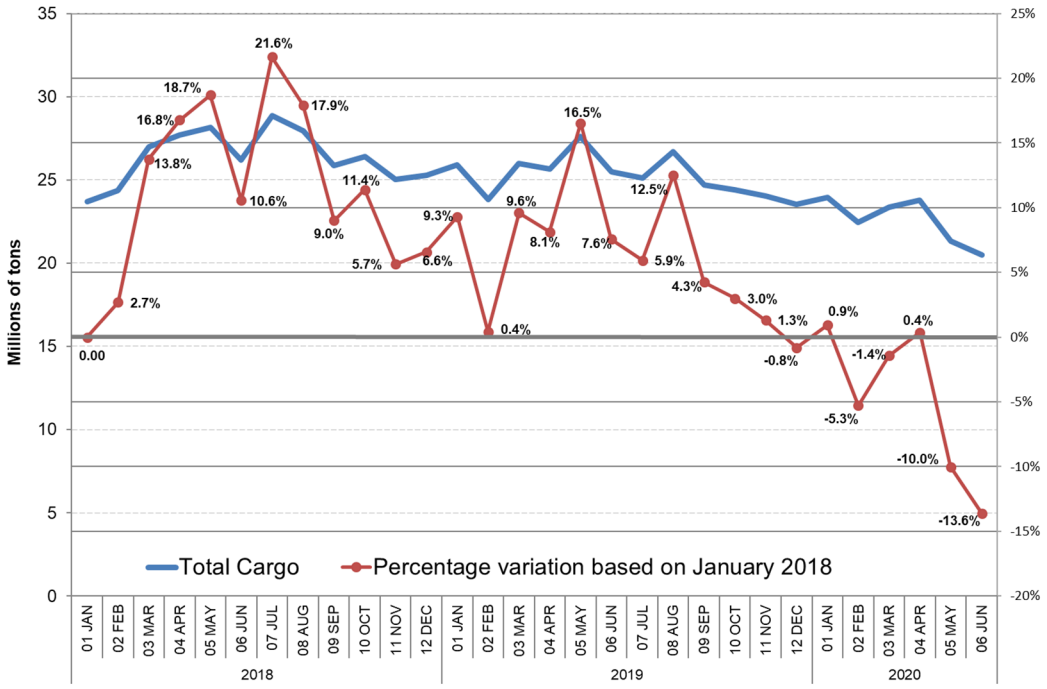


**Figure 2.** Monthly evolution of cargo moved through Mexican maritime ports (Martner and Pérez 2020).

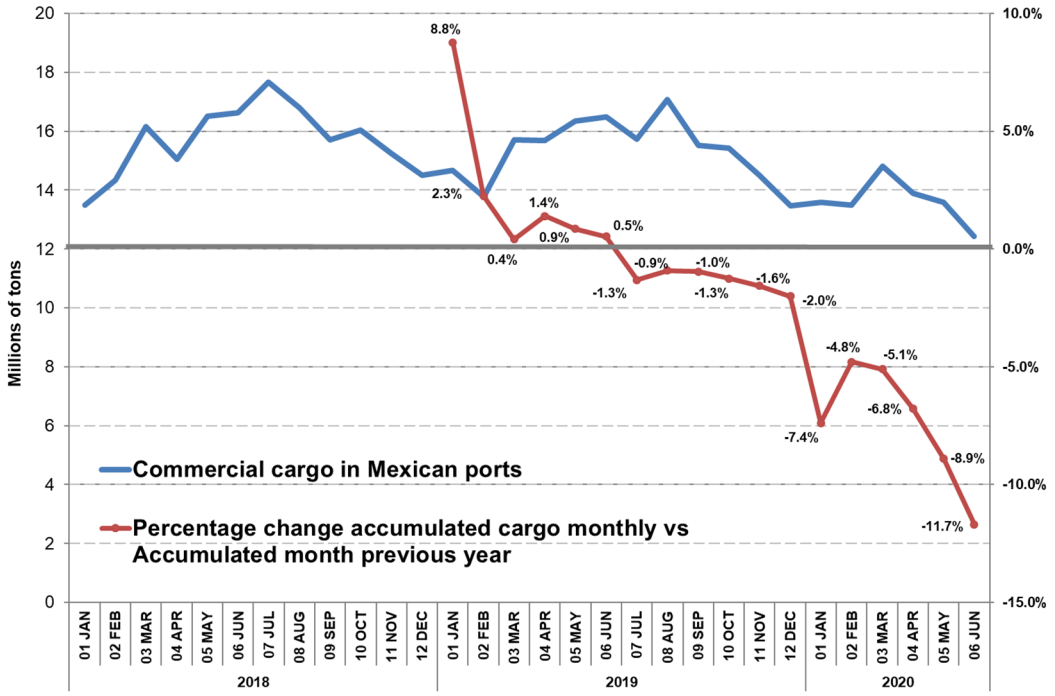


**Figure 3.** Monthly evolution of non-oil cargo moved through Mexican ports (Martner and Pérez 2020).

The progressive reopening of economic activities stimulated the recovery of the demand for shipments. Starting in June 2020, a significant recovery in cargo flows occurred in Mexican maritime ports, and even during the last quarter of the year, container movement exceeded that of 2019. This boost lasted during the first months of 2021, exceeding the level of cargo movement before the pandemic.

It is worth to note that this recovery process flow occurred even more strongly in developed economies, where there was a significant increase in the demand for manufactured goods (Altman and Bastian 2022; Zhao, Zhou, and Leus 2022). This caused new disruptions in maritime-port supply chains. Despite that, the COVID-19 pandemic was not defeated, and many activities remained restricted; paradoxically, the demand for durable consumer goods remained very high.

In this sense, the pandemic seemed to have a revealing impact, changing the population's consumption patterns. Given restrictions on services consumption (travel, vacations, recreational activities, sports, shows, culture, gyms, restaurants, cinemas, etc.), consumption focused on goods for confinement and work at home, for example, i) fitness equipment at home, ii) furniture and electronic equipment for work, iii) goods related to health care, and iv) articles for the prevention of contagion (Kohli et al. 2020; Larios-Gómez et al. 2021). Consequently, two logistics challenges occurred. On the one hand, there was a need for replenishing inventories of "*conventional*" products which were out of stock in the main markets. On the other hand, the growing requirements of other products resulting from the new consumption pattern had to be met (Nomikos et al. 2022).

*Supply shocks on maritime transportation*

A global perspective is needed to understand the supply shocks on maritime transportation in Mexico. A remarkable aspect of the crisis generated by COVID-19 has been the ability shown by regular shipping lines to adapt very quickly to market fluctuations while maintaining their profitability. When many analysts predicted a debacle in this sector due to the abrupt drop in trade flows and a collapse in rates, maritime companies showed remarkable flexibility by adjusting supply to demand and staying profitable (Kim 2019).

This reaction prevented the abrupt drop in rates, and even, in many of the main routes, a notable increase in freight charges happened. There are at least two relevant explanatory elements involved. On the one hand, the large consolidation process of the regular container shipping lines and the strategic alliances they formed allowed them to have a broader vision of the market. In addition, the digitization of operations has been a crucial factor in obtaining vast amounts of timely information that allowed them to adjust more quickly to fluctuations in demand.

In other words, there are now fewer shipping companies than a decade ago, but they are also part of large consortiums and/or alliances, which allows them to make decisions much more quickly. Additionally, they have more technological instruments to predict the behavior of demand. In effect, they can now know in advance exactly how many shipments their shippers are canceling and, based on this, cancel trips on scheduled routes (what is known as "*blank sailing"*), avoiding an oversupply of capacity that would collapse freight rates. However, as in all forecasts, uncontrolled elements arose, and on several routes, the demand, already erratic in times of pandemic, was higher than expected.

However, by the second half of 2020, given the explosive increase in demand coming from the gradual release of activities and the change in consumption patterns cited above, the supply trend changed substantially to the point that the supply of international maritime and intermodal transportation has not been able to adjust to such imbalances. In this way, there was a rapid drop in shipments in the first half of 2020, followed by an uncommon exponential growth in demand during the second half and all along the year 2021.

Thus, containers became scarce in the last quarter of 2020, and routes and space availability on ships were insufficient. Due to the increase in arrivals and the difficulties of the terminals dealing not only with the abrupt growth in the volume of work but also with the availability of the workforce, constantly reduced by the pandemic, the delays for the attention of the ships in the ports of destination grew enormously.

Even in the land part of the logistics-port chain, there were remarkable effects due to the lack of trucks and rail cars to meet the demand bubble of the first semester of 2023. As a result, the difficulties for just-in-time or just-in-sequence deliveries of inputs and products transportation were enormous.

This vicious circle observed in the lack of containers to ship the products, delays, congestion in the ports of origin and destination, lack of personnel, and insufficient availability of land transportation became evident in at least two substantive problems for maritime-port supply chains. On the one hand, the prices of maritime and intermodal services increased substantially, causing increases that triple and, on occasion, quadruple the rates for each container mobilized. On the other hand, a sharp drop in the reliability of vessel arrival times was notorious. Indeed, in 2018 and 2019, on-time arrivals of container ships were around 75 to 80% globally. However, as of August 2020, a sustained deterioration of this reliability indicator started, to the point that, in December, the index fell to 45% of on-time arrivals (see Figure 4). The latest data available,

corresponding to January 2021, reflects an even more significant deterioration in the reliability of on-time arrivals of container ships, at only 35%.

According to data provided by Sea Intelligence (Kasif 2021), the reliability of container shipping between Asia and the US was well below the world average. For the October to November 2020 period, on-time arrivals fell to 28.6% in trade between Asia and the US West Coast; there was a similar situation for trade flows between Asia and the US East Coast, with a reduction of 26.4%. Media reported that piles of container ships remained anchored for many days in areas such as the Bay of Los Angeles, waiting to be unloaded at the ports of Southern California (Stankiewicz 2021).

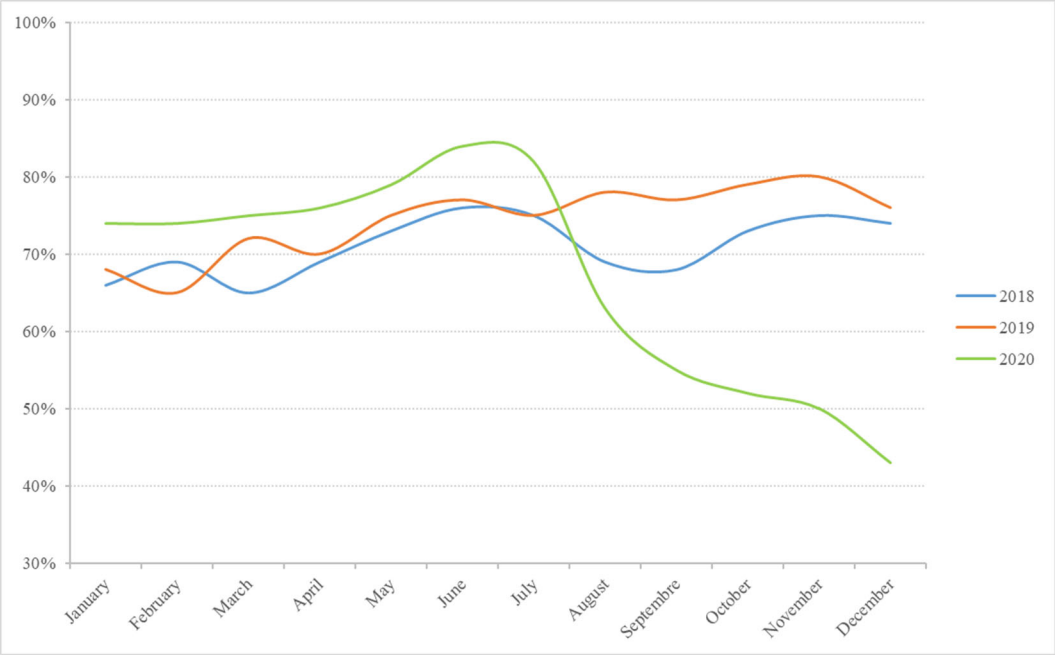


**Figure 4.** On-time arrivals of container ships at the global level, 2018 to 2020.

### *Air transportation*

In the case of air cargo in Mexico for the period before 2018, growth was observed. In 2019, there was a decrease (-5.5%) compared to 2018 (see Figure 5). In this case, the drop was due to weak growth in world trade, slowing global economic growth, and the effects of the trade war between the United States and China. In contrast, in 2020, the decline in these flows (-11.7%) can be attributed to the impacts of the COVID-19 pandemic.

The monthly detail of these flows appears in Figure 6. As can be seen, starting in March 2019 (green bars), a sustained decrease in air cargo flows in Mexico was observed. However, in 2020 (black bars), due to the impact of COVID-19, the drop is visible starting in March and is more acute in April. It is pertinent to note that as of May 2020, a sustained but slow recovery of these flows began to occur. It is essential to point out that, although there was a decrease in cargo flows in the months of January and February 2020, this was due to the trend originating in 2019 since the confinement in Mexico did not begin until the end of March 2020.

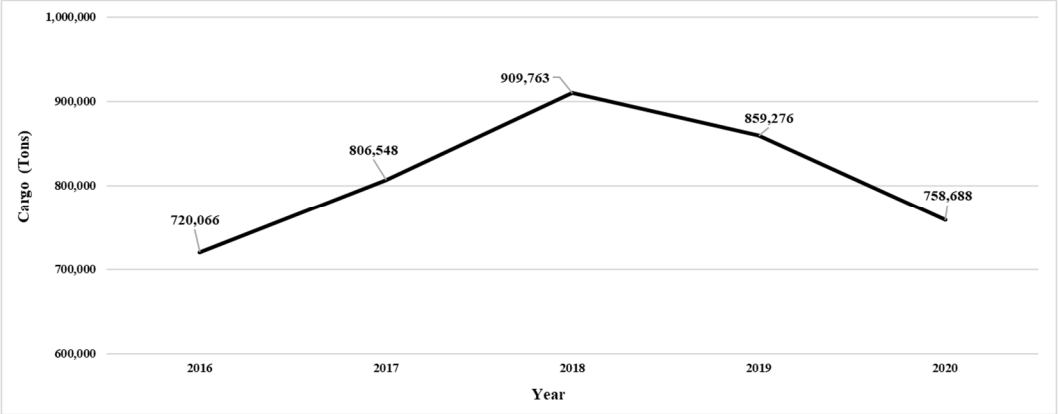


**Figure 5.** Annual air cargo in Mexico (2016 to 2020).[3]

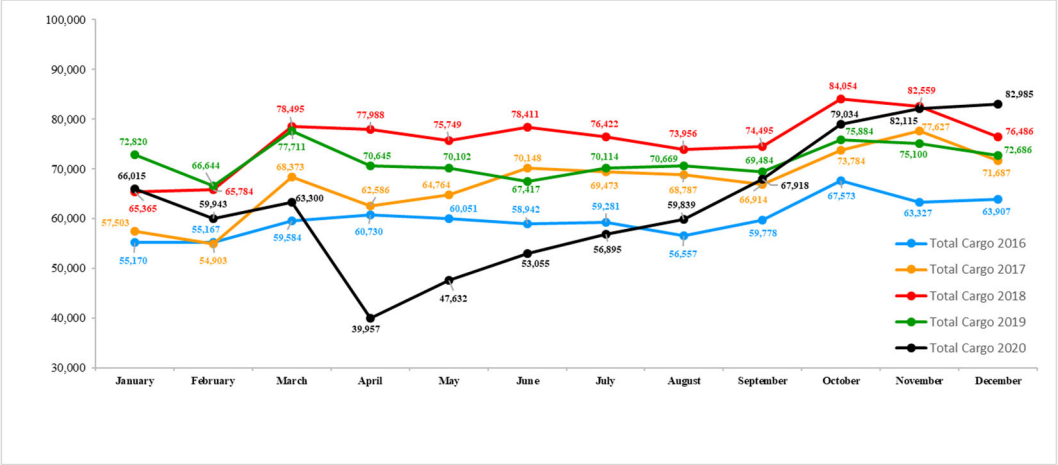


**Figure 6.** Monthly air cargo in Mexico (2016 to 2020).[4]

*Demand shocks on air transportation*

The visualization of the effect of the pandemic on cargo flows uses the percentage change by comparing its magnitudes month by month; that is, January 2019 against January 2020, February 2019 against February 2020, and so on. The results appear in Figure 5. In this case, although there was already a previous downward trend (nearly 10% per month in the first two months of 2020), as of March, the fall was more apparent since it exceeded 18% per month. However, in April, it was much higher because air activity had a significant reduction throughout the month; the foregoing is due to the confinement caused by the COVID-19 pandemic. Since September, a very significant recovery has been observed; and by October, the magnitudes already exceeded the values of 2019 (see Figure 6). As of May 2020, a slow but sustained recovery of air cargo flows occurs (see Figure 7).

[3] Own elaboration based on Operational Statistics of the Airlines of the Federal Civil Aviation Agency (AFAC): https://www.gob.mx/afac/acciones-y-programas/estadistica-historica-1992-2019-historical-statistics-1992-2019
[4] Ibid.

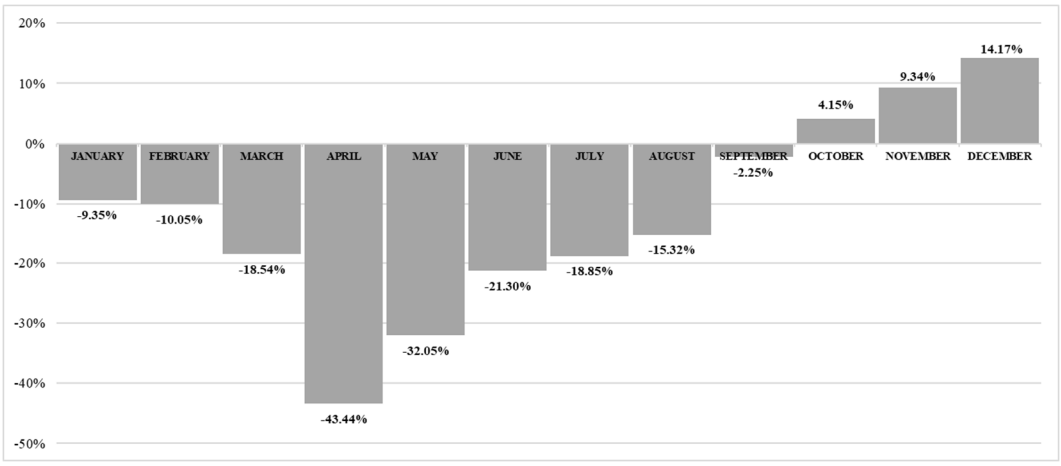


**Figure 7.** Percentage change rate of monthly air cargo in Mexico from 2020 to 2019.[5]

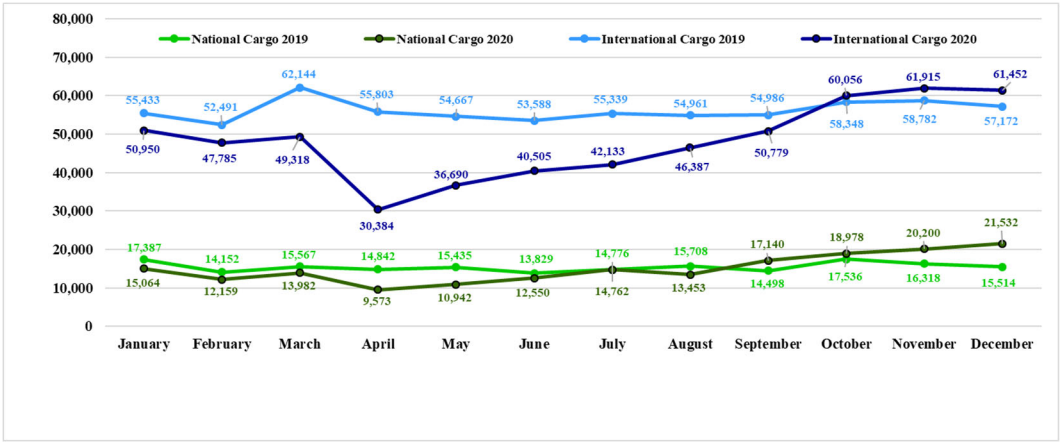


**Figure 8.** Monthly, national, and international air cargo (2019 to 2020).[6]

Analyzing, in a disaggregated way, the two main components of cargo flows, that is, domestic air cargo (domestic flights) and foreign trade cargo (international flights), Figure 8 shows domestic flights (green color) and international flights (blue color). For the year 2019, lighter colors were attributed to it, and for 2020, darker colors.

Figure 8 shows that although both cargo flows (domestic and foreign) have tended to decrease, the principal reduction occurred in international cargo. Domestic flows had practically reached the values of the previous year in July, and in September, they had already surpassed them. On the other hand, July's international cargo still showed a lag. However, by October, both domestic and international flows had already exceeded the respective values of 2019. In general, both cargo flows show a sustained recovery as of May 2020.

[5] Ibid.
[6] Ibid.

*Supply shocks on air transportation*

A high percentage of air cargo moves inside the cargo compartments of passenger flights. Fears of flying by passengers, and the decrease in social and economic activity derived from mobility restrictions that sought to reduce the spread of the pandemic, substantially reduced commercial passenger flights and, consequently, reduced the availability of space for air cargo transportation. Before the COVID-19 pandemic, belly cargo represented the higher part of air cargo in Mexico. In 2019, this percentage was around 59% of the total, with the remaining 41% served in dedicated freighters. Thus, at the beginning of the pandemic, the supply of air cargo transportation shrank suddenly and significantly.

Additionally, to reduce contagion within their territories, some countries chose to close their borders and airports to commercial passenger services. Thus, they reduced the supply of belly cargo services and the connectivity involved. For example, in the case of the top Mexican airport, the Mexico City International Airport (AICM), its main air cargo export destinations in economic terms in 2018 were the United States, the United Kingdom, Germany, Switzerland, France, Brazil, Colombia, and China (accumulating 77.6% of the total). In the case of imports, they were China, Germany, the United States, France, Italy, Switzerland, Japan, Spain, and Brazil, accumulating 73.5% of the total.

At different stages of the pandemic during 2020, many airports in the above countries closed. At the start of the pandemic, it was airports located in Asia; later, it was European airports; finally, airports in North and South America. This situation endured through the first months of 2021, mainly in some countries in Europe and in the Americas. It is worth noting that these closures contravened the recommendations established by the World Health Organization (WHO) since the beginning of the pandemic. The WHO recommended not to impose any restrictions on travel and/or trade (WHO 2020).

Also, due to the lack of equipment for air cargo movement during the pandemic, some airlines converted their passenger aircraft to freighters. Thus, for example, the company Viva Aerobus temporarily configured 10 Airbus A320 passenger aircraft to carry out 100% of the cargo flights. Each aircraft, taking advantage of the cabin space (seats) and lower compartments (hold), reached a capacity of up to 19 tons of cargo (ALN News 2020).

Despite this context, Mexico was one of the countries that recovered the fastest from the effects of the COVID-19 pandemic. One important factor in this regard is that, throughout the pandemic, Mexico did not impose restrictions on foreign airlines landing at its airports. Therefore, in April 2021, Mexico was the sixth country in the world with the highest percentage of its fleet in operation, 82.6%, only surpassed by China, Japan, Ethiopia, Taiwan, and the US (CH-Aviation 2021).

***Rail transportation***

By taking into account the main and secondary railroad tracks under concession, auxiliary (yards and slopes), and private railroad tracks, rail transportation in Mexico has a network of 23,400 km. According to an analysis by the OECD International Transportation Forum in 2014, Mexico´s rail network has the great advantage of connecting at least six points of the northern border with the tracks of the US and Canada. In fact, in March 2021, the Canadian company Canadian Pacific Railway Ltd. (CP) agreed to acquire the American company Kansas City Southern (KCS) for $25

billion dollars, which will create the only 32,000-kilometer railway network that crosses the three North American countries (Morales 2021).

The role of rail transportation in Mexico's integration into the global economy is essential. For industries such as the automotive one, the railway is an example of a win-win relationship between transportation and industry inside a supply chain. Specifically, yearly data related to cargo movements report that around 70% of the annual volume corresponds to flows linked to Mexico's foreign trade, where import flows are predominant.

Since the Mexican freight rail system mobilizes a great diversity of products with multiple origins and destinations, it is classified as a "*general cargo system.*" The efficiency of this non-mining railway system, with its complexity, exceeds the productivity of any of the general cargo systems in Latin America.

In contrast to the growing participation of the railway in Mexico's foreign trade, its contribution to domestic supply chains is reduced. Its advantages in terms of competitive costs over long distances, energy efficiency, and reduced environmental impact position it as an important alternative to road transportation. The monitoring of cargo transportation by rail during 2020 indicated that, in the first quarter of 2020, tons and ton-kilometers reported monthly growth and favorable rates compared to the same period in 2019 (see Table 1).

**Table 1.** Comparisons between the first quarter of 2019 and the first quarter of 2020.

| **Concept** | **Year** | **Accumulated to March** |
|---|---|---|
| Loaded rail cars (millions) | 2020 | 0.51 |
| | 2019 | 0.49 |
| Comparison % 2020 vs 2019 | | **4.08** |
| Tonnes (millions) | 2020 | 31.41 |
| | 2019 | 29.71 |
| Comparison % 2020 vs 2019 | | **5.7** |
| Tonne-km (millions) | 2020 | 22,304.55 |
| | 2019 | 20,419.89 |
| Comparison % 2020 vs 2019 | | **9.23** |

In the first quarter, 2019 and 2020 data reveal that the performance of the railway sector was positive. This is defined by comparing the same quarter between 2018 and 2019, which closed with decreases in the number of total transported tons and the number of rail cars loaded (2.19 million in 2018 and 2.09 million in 2019). In fact, in 2019, rail freight started and remained during the first half of the year below the levels reached in 2017 to 2018 (see Figure 9).

In the first quarter, comparing 2019 and 2020, the increase in traffic related to foreign trade also stands out. Both the transported tons and ton-km ratio (Figure 10) reported a rise in 2020 in terms of exports and imports.

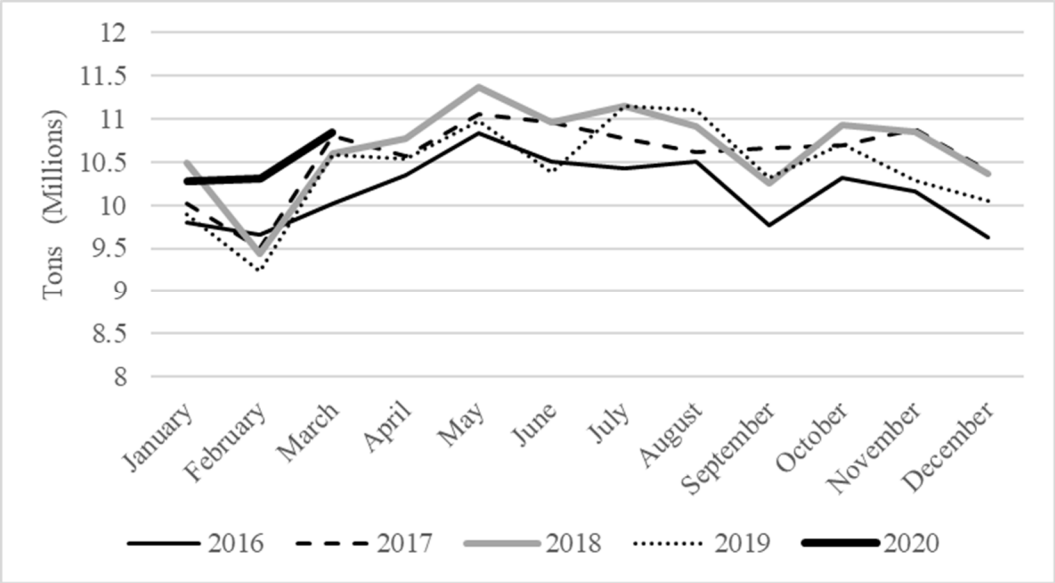


**Figure 9.** Monthly cargo transportation by the Mexican Railway System in the first quarter of 2016 to 2020 (ARTF 2020).[7]

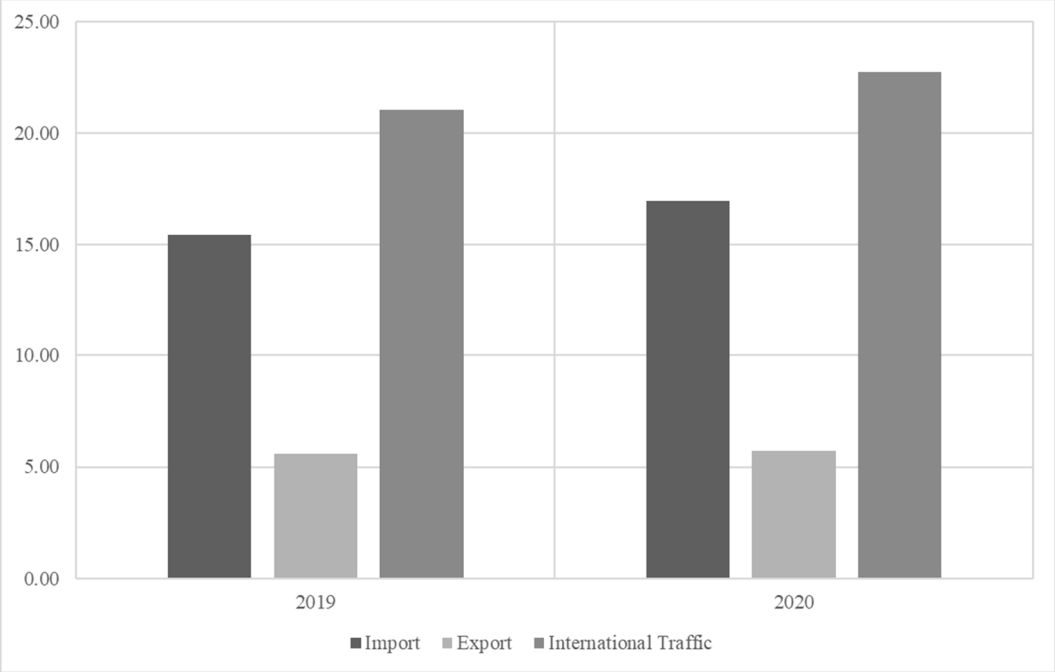


**Figure 10**. Cumulative foreign trade load as of March 2020 (millions of tons).

[7] Taken from the "Pulse of the Mexican Railway System March 2020" prepared and presented by the Railway Transportation Regulatory Agency of the Mexican Department of Communications and Transportation (SCT).

*Demand shocks on rail transportation*

The weekly data of the number of rail cars loaded provided by the Weekly Railroad Traffic (Weeks 1-13 of 2020) showed high variation. Some products reported growth in this period, for example: i) metallic and non-metallic minerals, ii) agricultural and food products, and iii) intermodal freight. Other types of cargo did not show variations concerning the same period of 2019, or they began to fall in the last three weeks of the first quarter. This is the specific case of automobiles and car spares that start 2020 with an interruption of the growth trend in Week 11 of the year (March), when the fall begins (see Figure 11).

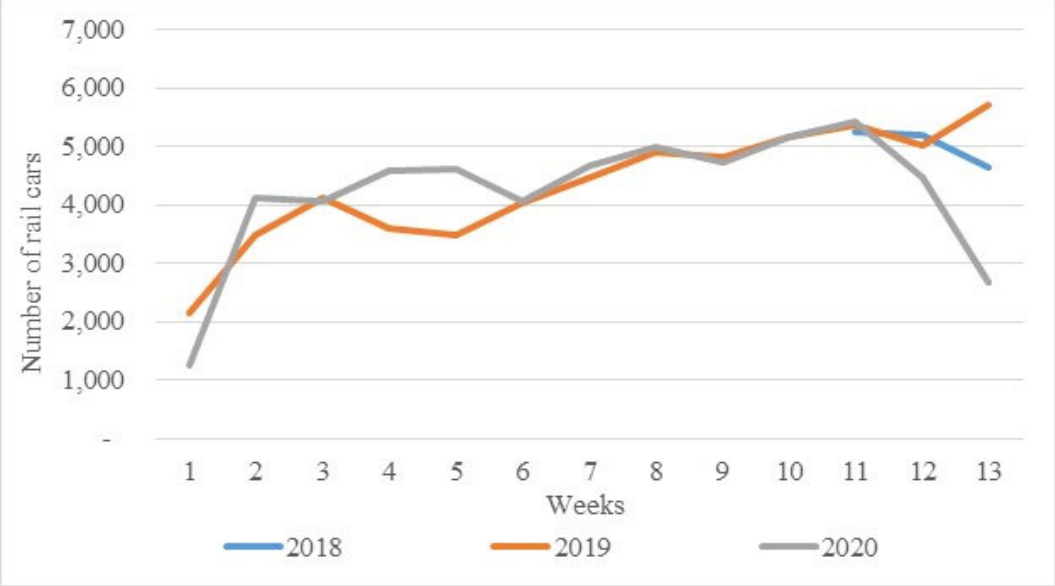


**Figure 11**. Weekly variation of vehicles and auto parts in the first quarter of 2019 and 2020.[8]

The situation from April to June 2020 was completely different from that of the previous quarterly period. Monthly data showed decreased transported tons, rail cars moved, and total ton-km. For example, the decrease from March to April was 1,156.7 million, compared to the first three months of the year (see Table 2).

The decrease in tons moved in the second quarter of 2020 resulted from the sharp economic slowdown, placing April, May, and June below the cargo levels of 2016 (see Figure 12). Although June shows a rebound, it is 1.0 million tons below June 2019, the lowest in 2016 to 2019.

The monthly percentage variation between 2018 to 2019 and 2019 to 2020 (see Figure 13) shows the proportion of the reduction in the second quarter of 2020 and the continued drop of 2019 concerning 2018.

A key segment of the railway sector was intermodal freight, which showed a significant drop in the second quarter of 2020. According to the Weekly Railroad Traffic from AAR, 2020 was placed with 36,114 units less than in 2019. This highlights an unfavorable international economic disruption, which somehow influences the effects caused by the pandemic.

[8] García-Ortega and Jiménez-Sánchez (2021).

**Table 2.** Comparisons at the end of the second quarter of 2019 and 2020.

| **Concept** | **Year** | **Accumulated to June** |
|---|---|---|
| Loaded rail cars (millions) | 2020 | 0.94 |
| | 2019 | 1.03 |
| Comparison %<br>2020 vs 2019 | | **-8.75** |
| Tonnes (millions) | 2020 | 58.96 |
| | 2019 | 61.59 |
| Comparison %<br>2020 vs 2019 | | **-4.27** |
| Tonne-km (millions) | 2020 | 42,306.67 |
| | 2019 | 43,260.88 |
| Comparison %<br>2020 vs 2019 | | **-2.21** |

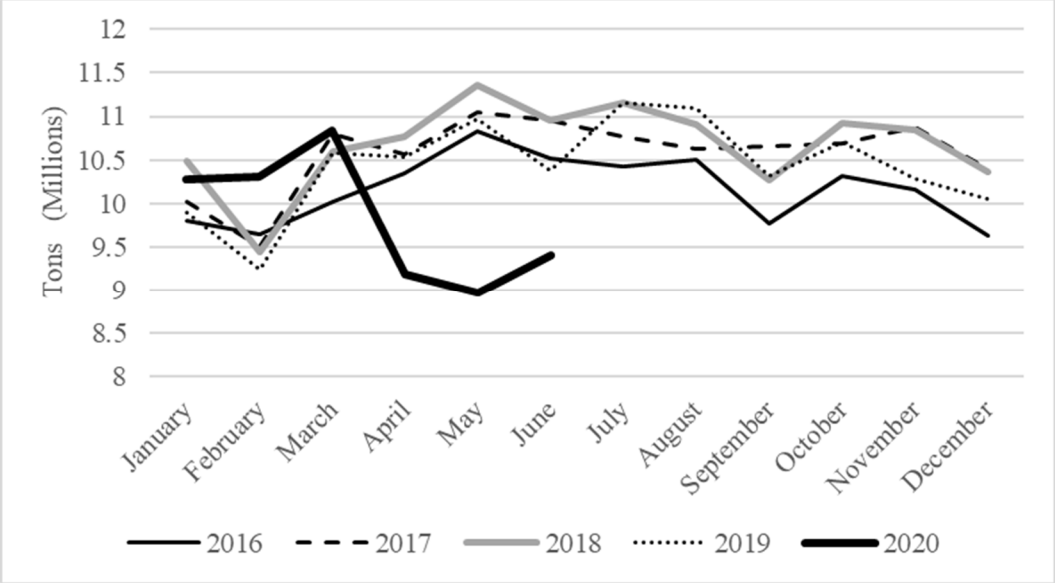


**Figure 12**. Monthly cargo moved by the Mexican Railway System in the second quarter of 2020 compared to what happened in 2016 to 2019.

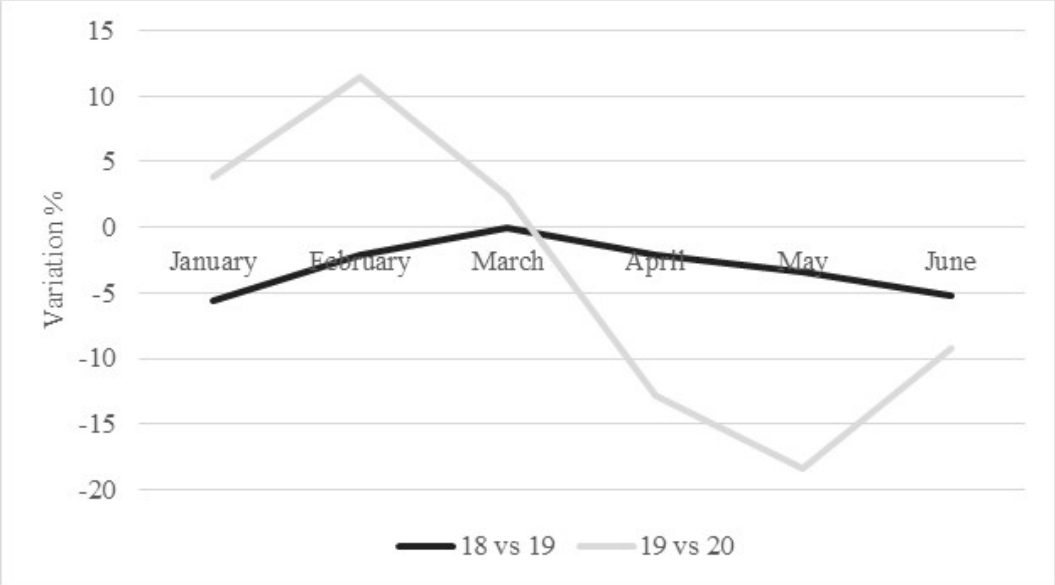


**Figure 13**. Monthly % variation of tons moved until the second quarter of 2018 to 2020.

That panorama was the same for all North American countries. Based on AAR data from August 2020, US rail traffic with Mexico and Canada had less activity in the first seven months of the year compared to 2019. Decreased trade in the economic region and declined industrial activity resulted from the COVID-19 pandemic. The total number of rail cars and intermodal units in the North American region was 11.6% lower than in 2019. The rail interchange between the US and Mexico dropped 10% in these seven months. Between Canada and the United States, the decrease was 8.5%, and inside the USA, 12.6%.

In Mexico, railway movements related to foreign trade showed an upturn by late September compared to the previous quarter. However, its proportion concerning the total cargo volume, registered in the first quarter of 2020, decreased from 72.3% to 69.9% in the annual accumulated to September, that is, at the end of the year's third quarter. The explanation comes from what happened in the North American economic region and that, in the case of rail transportation, led the concessionaire companies that operate in Mexico to take an interest in moving cargo from the national market.

During the last quarter of 2020, the increase in tons, ton-km, and the number of rail cars loaded concerning the two previous periods continued, and even November and December were above those of the previous year. However, at the end of 2020, the annual totals did not exceed those of 2019 (see Table 3).

Based on data from the AAR, Info-Transportaciones (2020) reported that the Mexican rail movement registered a contraction of 9.6% at the end of 2020 compared to 2019, while the decrease in North America as a whole was 6.8%.

**Table 3.** Comparisons of accumulated to December between 2019 and 2020.

| Concept | Year | Accumulated to June |
|---|---|---|
| Loaded rail cars (millions) | 2020 | 1.93 |
| | 2019 | 2.09 |
| Comparison % 2020 vs 2019 | | **-7.85** |
| Tonnes (millions) | 2020 | 120.38 |
| | 2019 | 125.19 |
| Comparison % 2020 vs 2019 | | **-3.84** |
| Tonne-km (millions) | 2020 | 86,223.63 |
| | 2019 | 89,049.39 |
| Comparison % 2020 vs 2019 | | **-3.17** |

*Supply shocks on rail transportation*

Rail freight services in Mexico are delivered by six companies. Three of them (Ferromex, Ferrosur, and KCSM) account for around 90% of the total cargo volume transported by rail. It is convenient to place this supply analysis at the end of 2019 (See Table 4).

**Table 4.** Annual cargo, local and remitted traffic (millions of tons).

| Companies | Annual | |
|---|---|---|
| | **2018** | **2019** |
| KCSM | 43.61 | 44.24 |
| FERROMEX | 61.79 | 59.9 |
| FERROSUR | 15.93 | 14.98 |
| TFVM | 2.56 | 2.15 |
| LCD | 3.46 | 3.11 |
| FIT | 0.53 | 0.65 |
| ADMICARGA | 0.16 | 0.14 |
| **Total** | **128.03** | **125.19** |

During the second and third quarters of 2020, all the railroad companies in the country registered a decrease in the volumes of cargo transported (tons), compared to the same period in 2019 (see Figure 14). It is, therefore, interesting to explore what measures each company adopted to solve or mitigate the effects of the COVID-19 pandemic beyond transportation being an activity classified as "*essential*."

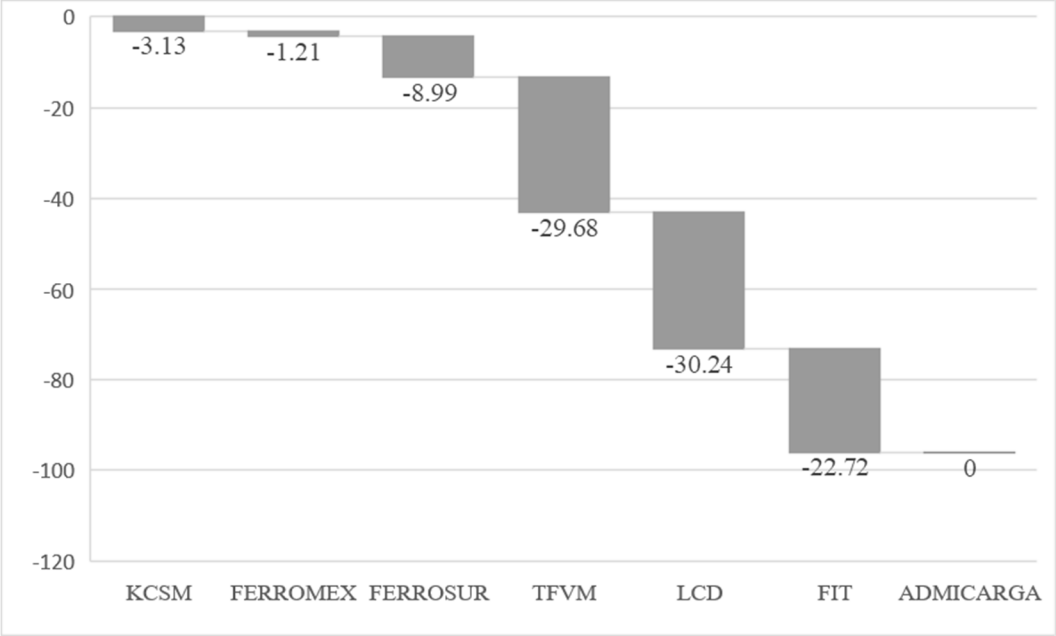


**Figure 14**. Percentage variation of tons in the second quarter of 2020 vs. 2019.

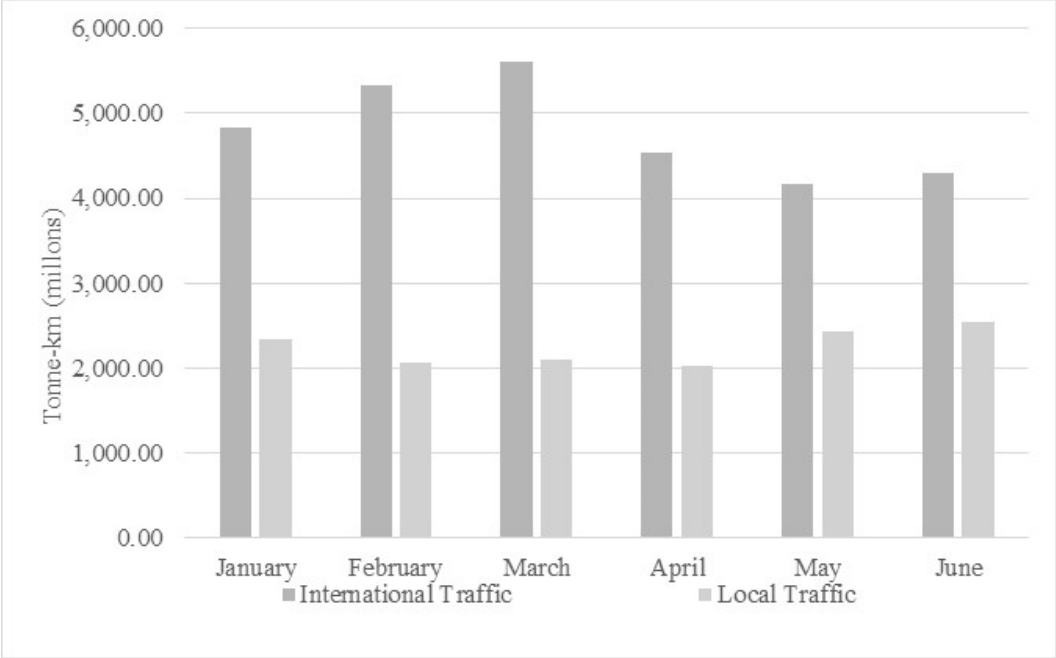


**Figure 15**. Local and international traffic, second quarter of 2020.

For example, Garcia (2020a) indicated that, although its revenues fell by 9.3% compared to the same period in 2019, not all its freight segments behaved the same. While the segments of energy, agricultural products, minerals, and chemicals contributed growing revenues of 12, 11, 6, and 5%, respectively, others like the automotive, intermodal, and industrial products registered falls of 74% in the first and 18% in the last two.

In the same way, the short-line railroad Tijuana-Tecate (ADMICARGA[9]) declared finding opportunities in the transportation of energy, while some of its traditional segments, linked to maquiladora labor (cattle feed, paper, wood, auto parts, and electronics), were unemployed before the closure of more than 1,500 factories located in Baja California (García 2020b).[10] Measures taken by the concessionaire companies of the freight rail service in Mexico to balance the effects caused in the different business segments (high impact in the automotive sector and less in the movement of grains and agricultural products) favored the increase in local or domestic traffic (see Figure 15).

In the case of the corporate Kansas City Southern (KCS), of which Kansas City Southern de México (KCSM) was part, given the 11.7% decrease in its income compared to 2019, it began in the second quarter of 2020 with measures that would allow it to reduce costs and strengthened more initiatives related to trains' consolidation. KCSM increased the length of trains and reduced crew costs. Thus, its operating expenses decreased by 27% due to lower fuel consumption, fewer personnel, and fewer hours worked. The railway's operating index in the third quarter was 58.8%, an improvement compared to 62.3% in 2019. Fuel savings were 41.6% since they spent 87 million dollars in 2019 and 50 million dollars in 2020 (T21, 2020). This fact could explain why KCSM is one of the concessionaires with the lowest percentage differences in its performance compared to 2019, -3.13% at the end of June, -2.48% in September, and -0.55% in December.

### *Road Transportation*

According to the General Direction of Federal Road Transportation (DGAF), in 2019, there were 181,031 for-hire carriers registered, of which 81.8% were micro-companies, 15.6% were small-companies, 2.0% were medium-sized companies, and just 0.6% were large companies. In this classification, micro-sized companies are those with a fleet of one to five vehicles; small-sized companies, from six to 30 vehicles; medium-sized companies, from 31 to 100 vehicles; and large companies with more than 100 vehicles. The road freight transportation sector is characterized as highly atomized and dispersed along the country and is the main mode of transportation.

More than 90% of the country's domestic land cargo in Mexico moves through road freight transportation (García-Ortega and Jiménez-Sánchez 2021). Its importance lies in its high level of accessibility to the most remote regions of the country and the versatility and flexibility of implementing door-to-door service in times of pandemic. Almost all the goods in the country move by this mode, particularly the food consumed by the population. Due to these characteristics, this sector is classified as an "*essential activity*" to face and help mitigate the COVID-19 pandemic.

*Demand shocks on road transportation*

The impact of the COVID-19 pandemic on road freight companies was the reduction in demand due to the stopping of activities declared non-essential. In the first half of 2020, the fall in the national GDP was -10.1%, while the GDP of the motor carrier sector reached -14.8%, according to the National Institute of Statistics and Geography (INEGI) database (see Figure 16).

[9] Source: http://www.fcbc.com.mx/

[10] In the words of the president of KCSM, "The railway has the advantage of serving different sectors, if one decreases, the others can grow or remain." The Mexican Railway System has shown resilience in the face of the pandemic; its ability to transport different types of products has mitigated the adverse effects. Although it suffered a drop in freight transportation, such as the automotive, grains, and other essential products, it remained strong.

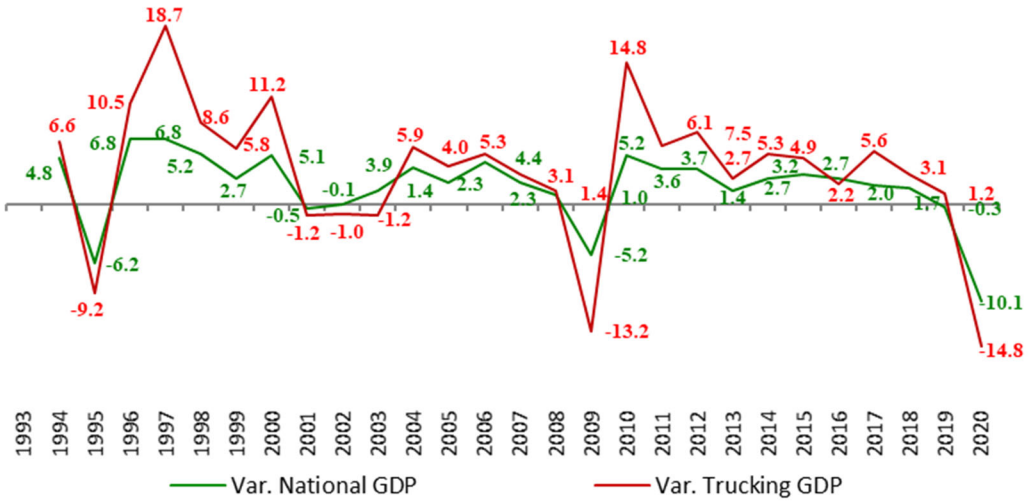


**Figure 16**. National GDP vs. GDP of the motor carrier sector.

According to McKibbin and Fernando (2020): "…Transport being limited and even restricted among countries has further slowed down global economic activities. Most importantly, some panic among consumers and firms has distorted usual consumption patterns and created market anomalies."

As ECLAC (2020) mentioned, "…the closure of productive activities, the strictest sanitary measures, and administrative obstacles have slowed down land transportation. Even though trucking is crucial to meet the demand for essential items, there is less activity due to the pandemic. Globally, it is expected that the decrease in the annual turnover of companies in the sector in 2020 will be around 18%; in Latin America, it will reach 20%". According to this organization, these projections are consistent with the drop in the volume transported during the first half of 2020. In the case of Mexico, ECLAC estimated a decline of -45% in the volume of goods transported by truck.

The COVID-19 pandemic negatively affected the global economy, and its effects continued during 2021. According to INEGI, by the third quarter of 2020, the national GDP had shown a contraction of -9.6%, while the GDP of the freight transportation sector presented a decrease of -12.8%. These figures support that, since the transportation activity derives from the demand of the different sectors, the pause of activities considered "*non-essential*" at the beginning of the pandemic greatly impacted the demand for freight transportation.

It is worth noting that most economic activities reduced their activity to above two digits. Some reached contractions of a little more than -40.0%, significantly affecting the use of the cargo trucking fleet. Thus, for example, the following are among the economic activities most affected by COVID-19 and in which transportation is a vital part of the supply chain. The manufacture of footwear reduced by -40.3%; leather and fur tanning and finishing, leather manufacture, and fur and substitute materials decreased -38.6%; clothing manufacturing reduced by -37.8%; food and beverage preparation services diminished -31.7%; and the manufacture of automobiles and trucks decreased by -28.8%, among others.

Regarding foreign trade, according to INEGI, by June 2020, the value of merchandise exports reached 33,076 million dollars—a figure composed of 31,818 million dollars of non-oil exports

and 1,258 million dollars of oil companies. Thus, total exports showed an annual decrease of -12.8%, resulting in reductions of -11.6% in non-oil exports and -35.6% in oil exports. Within non-oil exports, those directed to the USA fell at an annual rate of -7.9% and those channeled to the rest of the world did so by -28.0%.

According to CANACAR (2020), of the 1,523 companies analyzed by their study, on average, 86.6% reduced their billing while 12.7% kept it unchanged, and only 0.7% showed an increase in it. In the latter case, companies with courier and parcel operations stand out. Faced with the economic crisis generated by the COVID-19 pandemic, many freight transportation companies stopped their activities, above all, micro-enterprises, which expectedly will have a slow recovery post-COVID-19, mainly because they rely heavily on non-essential activities.

*Supply shocks on road transportation*

The quarantine decreed as mandatory for March and April of 2020 paralyzed manufacturing, commercial, and service activities, which caused an unprecedented negative economic impact in various sectors, including road freight activity. A shortage of personnel (either due to health impacts for the operators or due to layoffs derived from the drop in demand) increased prices in the availability of transportation equipment. This influenced the National Producer Price Index (INPP) published by INEGI. Specifically, the item "*Transportation, mail and storage activities*" increased by 2.75% from April 2020 to the same month of 2021.

The challenges faced by road freight transportation companies entailed negative impacts on the supply of services, among them (De Buen 2020):

- Disruption of some services due to lack of personnel.
- Delays due to processes that looked to guarantee continuity of operations, but at the same time, safety and health for drivers.
- Prioritization of the provision of vehicles dedicated to health emergency care, as well as the supply of food and basic needs.
- Delays due to training personnel to face more complex management, subject to different pressures and challenges (health, operational, security, etc.).

However, there were also positive impacts on supply:

- More favorable operating conditions (higher speeds, reduced congestion, etc.).
- Reduction of delays in routes and, therefore, of greenhouse gas emissions.
- Better perception of the image of logistics and freight transportation service providers, contributing to facilitating processes involving the authorities and society.
- Reorganization of supply chains that allowed a more efficient provision of transportation services.
- Partial or total suspension and rescheduling of non-priority works allowed a greater fluidity of freight transportation on roads.
- Interest in greater coordination between ministries and authorities of different levels of government to facilitate the development of logistics activities.
- Increase in the interest of the different logistics actors in analyzing large masses of data (big data) to better understand the reasons that cause bottlenecks in the transportation infrastructure.

In this last point, the Mexican Institute of Transportation (IMT) proposed the creation of a National Centre for Intelligence and Innovation in Logistics (CeNIT-Logistics) in Mexico. Based on this new center, public and private actors would have freight flow data in real-time to optimize their freight transportation routes, considering the prevailing traffic conditions and the road repair in progress and regulations applicable to freight transportation (Cedillo-Campos 2020a, 2021).

## V. Conclusions

The COVID-19 pandemic has posed critical challenges and lessons for improving transportation processes for a more flexible and resilient operation. Among them are the creation and/or application of contingency plans (Cedillo-Campos 2020b), the prioritization of essential services, the reorganization of operations considering working conditions by health protocols, and lastly, the development of digitization strategies and information exchange using distributed platforms that promote the collective intelligence of operations (Cedillo-Campos 2020c).

The COVID-19 pandemic highlighted the vulnerabilities of global supply chains and their need for resilience and flexibility in the transportation sector. It also represented an opportunity to analyze transportation systems under exceptional operational conditions and to better understand how logistics technologies (*logistechs*) could be supportive in front of unexpected disruptions. Although this document identifies the impacts generated by the COVID-19 pandemic on the supply-demand relationship of freight transportation in Mexico, it does not analyze the impacts on specific chains, such as food and industrial chains. This is a limitation to highlight since the effects have been very distinct. This segmentation has different impacts on the type of transportation.

Thus, some similarities and differences appeared in the impacts on the supply and demand side for all four modes of transportation. Among the similarities observed were the following:

- Maritime, air, rail, and road transportation showed decreases in their cargo flows in the year before the pandemic due to the slowdown in world economic growth and the effects of the trade war between the United States and China.
- The most significant percentage of air and rail cargo flows was foreign trade. In the case of the air mode is 77%, and in the case of the railway, between 70% (in 2019) and 60% during the pandemic (2020).

Among the differences detected were:

- On the one hand, in air freight transportation, the impact of the COVID-19 pandemic performed as an asymmetric "V." That is an accelerated, significant, and sustained recovery but slow.
- On the other hand, in the case of Mexican road transportation, the impact had a "W" shape, with fluctuations in its trend.

Related to the use of logistics technologies (*logistechs*) to improve the resilience of Mexican freight transportation as a system, our research detected that they can be vital in optimizing shipping routes, reducing wait times, and minimizing disruptions caused by economic fluctuations, policy changes, and natural disasters. By leveraging "*logistechs*" such as robotics, artificial intelligence, the Internet of Things, big data analytics, and blockchain, they can help manage the challenges

faced by the maritime, air, rail, and road transportation sectors. These exponential technologies can improve the efficiency and dependability of transportation systems (Covarrubias and Cedillo-Campos 2023), making them more resilient during supply chain disruptions like the pandemic. However, analyzing specific supply chains' impacts is essential, considering the differences in the transportation modes and the asymmetry of the pandemic's impact.

### *Maritime transportation*

Regarding the impacts on maritime transportation on the demand side, its erratic behavior during the COVID-19 pandemic was established. However, it was possible to distinguish at least two markedly opposed tendencies. On the one hand, a drastic drop in cargo during the first half of the year, and on the other, an exponential growth in demand during the second half of 2020 (which continued throughout 2021) derived from the gradual release of activities.

Nevertheless, it is, above all, the change in consumption patterns that caused notable imbalances in globally extended supply chains, which have unhinged international maritime and intermodal transportation networks. However, this demand bubble did not sustain beyond 2021 because as countries controlled the effects of the pandemic (via mass vaccination programs and health measures), seasonal fluctuations in demand disappeared.

Regarding the supply-side impacts on shipping, as UNCTAD (2020) points out, a review of capacity management plans and changes to shipping schedules are key features of adjustment measures of supply introduced by shipping companies in the face of fluctuations in demand. In this sense, the digitization of interactions and the exchange of information has been essential for the continuity of maritime transportation operations during the pandemic. However, this has been insufficient to resolve the disruptions due to the excess container demand in recent months, equally by the delays and port and land congestion of the intermodal chains. Other "*logistechs*" that would improve resilience in maritime transportation are blockchain, the Internet of Things (IoT), and artificial intelligence (AI). They expand data analytics and predictive modeling capabilities to optimize shipping routes and reduce delays caused by port congestion and quarantine measures. Specifically, they can deliver real-time visibility and tracking of every container and then ensure that the flow of goods remains uninterrupted, even during times of crisis.

Likewise, shippers and ports have worked to address onshore operations, but the ability to adapt has not always been effective. It is becoming increasingly clear that to respond to the challenges such as COVID-19, it is necessary to develop a systemic vision of the entire maritime-port logistics chain beyond navigable sections and ports and a "*logistechs*" strategy.

Given the above, it is advisable to develop a better capacity to coordinate with the authorities of the different levels of government. Equally important is developing capabilities and processes and adopting "*logistechs*" to improve communication with other actors on the landside throughout the chain. Although it is a considerable challenge, building resilient networks in a highly volatile and changing environment is essential.

One of the most critical trends will be to improve real-time traceability and visibility for each link in maritime transportation. The COVID-19 pandemic has shown the importance of making quick decisions regarding potential obstacles, delays, cost overruns, and losses in value for the local, regional, and national economy.

### *Air transportation*

Regarding the impacts on air transportation on the demand side, the coronavirus pandemic significantly impacted aviation in Mexico in 2020. This was evident by an 11.7% reduction in cargo handled compared to 2019. Although the observed effect of the pandemic on aviation in Mexico was in the form of an asymmetric "V," where the fall was accelerated and significant, the recovery was sustained but slow.

The greatest impact occurred in April 2020, since there was a 43% reduction in air cargo flows. However, the cargo recovery was relatively fast. On one side, this was due to the increased demand of the health sector when countries faced the pandemic's effects. On the other side, it was due to the growth of electronic commerce that was driven by the quarantine of people during the pandemic.

Regarding the impacts on air transportation on the supply side, the restrictions imposed by various countries, for example, the closure of airports or the establishment of quarantines for travelers, reduced travel demand. This resulted in a series of reorganizations, which reduced the number of actors in the air transportation sector. Air transportation in Mexico contributed significantly to providing hospital supplies (respirators), medical equipment (masks, gloves, gowns, etc.), medicines, and, once developed, vaccines and active components for vaccine preparation. Regarding vaccines and their active substance, all the shipments arrived from Belgium, Argentina, China, India, Russia, the United States, the United Kingdom, Germany, and Korea.

The exceptional pressure on national governments to reduce the health effects on the population resulted in non-collaborative situations. The international cooperation system showed its limits. Since an exceptional shortage of medical supplies appeared, several national governments decided to proceed aggressively to take control of pharma stocks. Consequently, most governments used their national airlines to control air transportation freight flows. This situation exposed the strategic importance of air transportation when facing humanitarian emergencies.

Thus, this work detected that to improve the resilience of air transportation, "*logistechs*" such as robotics and artificial intelligence could be applied (Covarrubias, Cedillo-Campos, and Lozano, 2023). On the one hand, by avoiding human intervention, robotics can diminish the spread of diseases and, at the same time, facilitate autonomous cargo handling, reducing the time it takes to load and unload cargo and minimizing passengers' time in the airport. On the other hand, artificial intelligence can help airlines manage their inventory more efficiently, allowing them to adjust their cargo-handling capacities in response to sudden changes in demand. Consequently, air companies can better handle similar events in the future, reducing their vulnerability to risk and improving their ability to bounce back quickly.

### *Rail transportation*

The monthly relationship between the volumes of tons transported by the railway in 2019 and 2020 allowed identifying that the most acute differences occurred in April and May. May being the month from which the negative difference decreased until it became positive again. However, it is important to point out that the total annual tons of the year 2020 did not go back to the level of 2019, remaining 3.84% below.

After the fall in the second quarter of 2020,[11] rail freight slightly recovered month by month. This placed it in a stable condition, with around 10 million tons between June and October of the

[11] In this quarter, according to INEGI data, the country's economy fell 21.6% in real terms, compared to the same period of the previous year.

analyzed year, 2020. Although, in five months (January, February, March, November, and December 2020), cargo volumes exceeded those corresponding to 2019, these could not offset the effects of the sharp drop from April to June.

Regarding the impacts on rail transportation on the supply side, besides the consequences of the COVID-19 pandemic and the global economic slowdown of 2019, there were long blockades of the railways located in the states of Chihuahua, Sonora, and Michoacán during the second half of 2020. However, the domestic flow increased.

Of the two large groups into which rail cargo is divided, one linked to foreign trade (international traffic) and one linked to domestic movements (local traffic), the ratio of cargo volume handled is, in general terms, 70 and 30%, respectively. During 2020, international traffic decreased its participation in the last two quarters to 60% due to the slowdown experienced by global trade. This fact motivated a growing offer of services to move domestic cargo by railway companies. This type of movement increased by 40% in the second half of the year in compensation for the imbalance in international flows.

The greater regularity of the monthly tons of domestic traffic compared to international traffic indicates that at the end of the year, the difference between local traffic was -2.0% (36.9 million tons in 2019 and 36.16 million in 2020). Meanwhile, in the volume of international traffic, it was -4.6% (88.29 million in 2019 and 84.22 million in 2020). The quarterly differences of both traffic types between 2019 and 2020 show a positive difference in international movements in the first quarter, as well as the sharpening of its fall and the lower recovery of this traffic concerning local movements.

Faced with the crisis caused by COVID-19, rail transportation fulfilled its purpose, transporting essential goods, grains, various foods, and fuels, and the supplies and goods that transformation activities required and produced as the health emergency evolved throughout 2020. During that year, railway companies showed adaptation capacities in terms of productive efficiency, rapid changes in the cargo segments served, and in the proportion of international and domestic traffic flows; thus, they showed flexibility.

The responses from the railway sector suggest that rail transportation can face future risks of planetary magnitude, such as COVID-19. However, a continuous improvement process is always needed. Consequently, our research identified that three logistics technologies (*logistechs*) can be used to improve resilience in rail transportation in Mexico. First, the Internet of Things (IoT) can deliver real-time monitoring of cargo flows, especially when trying to avoid unexpected disruptions. Second, artificial intelligence (AI) can be used for predictive maintenance and decision-making to enhance efficiency and avert breakdowns. Third, 3D printing can deliver replacement parts on demand, diminishing the need for a large inventory and minimizing downtime, that is to say, the MRO (maintenance, repair, and operations) supply chain (Covarrubias, Cedillo-Campos, and Lozano 2023).

### *Road transportation*

In Mexico, as in most countries, the freight road transportation sector was managed as a national priority, especially in sectors such as pharmaceuticals, food, and agriculture. Road freight transportation was successful in retaining its workers. This contributed to five months of employment recovery as of July 2020.

However, at the beginning of the pandemic, there was a lack of protocols and/or quick guides to protect drivers and all the people involved in the logistics of road freight transportation. In this

sense, authorities and companies rapidly delivered coordination protocols to guarantee the continuity of operations. Nevertheless, the need for digitization of the process was clear. Based on Covarrubias (2021), our work identified that autonomous trucks, big data analytics, and blockchain are three exponential technologies that can improve road freight transportation in Mexico. First, autonomous trucks reduce human contact and increase the logistics efficiency of freight transportation processes. Second, trucking companies can employ big data analytics to optimize logistics routes, lowering the need for unnecessary travel and minimizing disruptions. In this sense, technological platforms known as "*control towers*" that allow "*door-to-door*" visibility of transportation flows, both individually for each company and globally (for authorities), are becoming essential for faster and more precise decision-making. Third, blockchain can provide greater transparency in supply chain management, allowing more precise tracking of shipments and enhancing the resilience of the road transportation industry (Covarrubias and Cedillo-Campos 2023).

***Future work***

The future work of this research should include three main aspects. First, to analyze the impacts on specific chains since the impacts on transportation have been very different. Second, to establish and discuss with federal public decision-makers an agenda for designing different pilot tests involving various "*logistechs*" as a first step to improve resilience. Third, to investigate whether, due to the pandemic, there have been transfers or adjustments among the modes so that certain chains that used one mode have preferred to switch to a different mode to better adapt to the changing reality.

**Funding**
The authors thank the Mexican Institute of Transportation for supporting this research (TI 14/20) and Texas A&M International University, A.R. Sanchez, Jr. School of Business, Texas Center for Border Economic and Enterprise Development.

**Acknowledgments**
The authors would like to thank the Mexican Department of Communications and Transportation agencies for their availability to share the information requested for this article. Likewise, we thank the transportation associations that kindly agreed to provide the information required to complement our work. Finally, to our colleague, Eric Moreno, who provided valuable comments to improve this document.

Nevertheless, it is important to clarify that the authors retain full responsibility for any prevailing flaw or omission in the document.

**References**

ALN News. 2020. "Viva Aerobus configures flights 100% focused on Cargo." *ALN News*, April 17, In Spanish [Online]: https://aerolatinnews.com/aerolineas/viva-aerobus-configura-vuelos-100-enfocados-en-

carga/#:~:text=Con%20el%20objetivo%20de%20adaptarse,para%20realizar%20vuelos%20100%25%20cargueros.
Altman, S., and P. Bastian. 2021. "The State of Globalization in 2021." *Harvard Business Review*, March 18 [Online]: https://hbr.org/2021/03/the-state-of-globalization-in-2021. Retrieved on 31 July 2021.
Altman, S., and P. Bastian. 2022. "The State of Globalization in 2022." *Harvard Business Review*, April 12 [Online]: https://hbr.org/2022/04/the-state-of-globalization-in-2022. Retrieved on 25 April 2022.
ARTF. 2020. "Pulse of the Mexican Railway System." Agencia Reguladora del Transporte Ferroviario, April 23, In Spanish [Online]: https://www.gob.mx/artf/acciones-y-programas/pulso-del-sector-ferroviario-marzo-2020#:~:text=Transporte%20de%20pasajeros-,En%20el%20periodo%20enero%2Dmarzo%20de%202020%20se%20movilizaron%20un,%25%20con%20respecto%20a%202019).
Blair, Tony. 2020. "The World Was Not Prepared for Covid-19. We Should Learn the Lessons and Change." Tony Blair Institute for Global Change, May 5 [Online]: https://www.institute.global/insights/public-services/world-was-not-prepared-covid-19-we-should-learn-lessons-and-change. Retrieved on 11 November 2021.
Boudette, N. 2017. "Ford cancela la construcción de una fábrica en México tras las críticas de Trump." *New York Times*, January 3 [Online]: https://www.nytimes.com/es/2017/01/03/espanol/ford-cancela-la-construccion-de-una-fabrica-en-mexico-tras-las-criticas-de-trump.html#:~:text=Ante%20las%20cr%C3%ADticas%20de%20Donald,aumentar%20su%20producci%C3%B3n%20en%20Michigan. Retrieved on 12 October 2021.
Bueno-Solano, A., and Cedillo-Campos, M. 2014. "Dynamic impact on global supply chains performance of disruptions propagation produced by terrorist acts." *Transportation Research Part E: Logistics and Transportation Review* 61 (January): 1-12. DOI: 10.1016/j.tre.2013.09.005.
CANACAR (National Chamber for Road Freight Transportation). 2020. *National survey for measuring the effects of COVID-19 on the road freight transportation*. Performed from 15 to 30 April 2020. México. In Spanish.
Caprice, C., and Phadnis, S. 2013. "Strategic Issues Facing Transportation, Volume 1: Scenario Planning for Freight Transportation Infrastructure Investment." *NCHRP Report 750.* Transportation Research Board, National Cooperative Highway Research Program, Washington, D.C.
Capurro, D. 2017. "Donald Trump's trade policy is driving Latin America into China's arms." *The Telegraph*, January 17 [Online]: https://www.telegraph.co.uk/news/2017/01/17/donald-trumps-trade-policy-driving-latin-america-chinas-arms/. Retrieved on 12 October 2021.
Castells, M. 2010. "Globalization, Networking, Urbanisation: Reflections on the Spatial Dynamics of the Information Age." *Urban Studies* 47 (13): 2737–2745. DOI: 10.1177/0042098010377365.
Cedillo-Campos, M. 2020a. "Creation of a National Centre for Intelligence and Innovation in Logistics (CeNIT-Logistics)." Presentation to Secretary of the Mexican Department of Transportation. February 4, Mexico City, Mexico.
Cedillo-Campos, M. 2020b. "7 Acciones para que tu cadena de suministro sea más resiliente." The Logistics World, August 19 [Online]: https://www.youtube.com/watch?v=DaCx7xXJETU. Retrieved on 12 October 2021.

Cedillo-Campos, M. 2020c. "Web platform to develop collective intelligence in logistics for Latin American SMEs: the case of SmartLogistiX3.com." *Nova Scientia* 12 (25): 1-29.

Cedillo-Campos, M. 2021. *New industrial order: The logistical value of infrastructure*. Independently Published, In Spanish [Online]: https://rb.gy/vteepi. Retrieved on 11 November 2021.

Cedillo-Campos, M., Pérez-González, C., Piña, J., and Moreno, E. 2019. "Measurement of travel time reliability of road transportation using GPS data: a freight fluidity approach." *Transportation Research Part A: Policy and Practice* 130 (December): 240-288. DOI: 10.1016/j.tra.2019.09.018.

Cedillo-Campos, M., Sánchez, C., and Sharada, V. 2012. "Reverse globalization and near-sourcing strategies: Impacts of crossing times at U.S.–Mexican border on cross-border supply chains." *Working Paper*, COMIMSA, National Council of Science and Technology in collaboration with MIT-Zaragoza Logistics Center and Texas A&M Transportation Institute, Mexico.

Cedillo-Campos, M., Sanchez, C., Vadali, S., Villa, J., and Menezes, M. 2014. "Supply chain dynamics and the 'cross-border effect': The U.S.–Mexican border's case." *Computers and Industrial Engineering* 72 (June): 261–273. DOI: 10.1016/j.cie.2014.03.015.

CH-Aviation. 2021. "Comparative statistics." CH-Aviation, April 22 [Online]: https://about.ch-aviation.com/blog/2021/04/22/the-number-of-worldwide-active-fleets-continue-to-stagnate-in-april/.

Covarrubias, D. 2021. "Port Laredo: The Million Mile Logistechs Hub." *Laredo Morning Times*, September 13, p. B3.

Covarrubias, D., and Cedillo-Campos, M. 2023. "A Living Lab at the Southern Border." *Wilson Quarterly* (Winter). Retrieved from https://www.wilsonquarterly.com/quarterly/strategic-competition/a-living-lab-at-the-southern-border.

Covarrubias, D., Cedillo-Campos, M., and Lozano, H. 2023. "Smart Borders: The key to more resilient International Trade and Cross-Border Transportation." *TCBEED Working Paper Series, TXCWP-2023-001*. Texas Center for Border Economic and Enterprise Development, Laredo, Texas. Retrieved from http://texascenter.tamiu.edu/PDF/WPS/txcwp-2023-001.pdf.

Crabtree, J. 2020. "China's Radical New Vision of Globalization." *NOEMA*, December 10 [Online]: https://www.noemamag.com/chinas-radical-new-vision-of-globalization/. Retrieved on 11 November 2021.

Crotti, D., Ferrari, C., and Tei, A. 2022. "Understanding the impact of demand shocks on the container port industry." *Maritime Economics & Logistics* 24 (4): 778-805. https://doi.org/10.1057/s41278-022-00222-0.

De Buen, O. 2020. "The COVID-19 pandemic: challenges and implications for roads and transportation." In Spanish. Conference, College of Civil Engineers of Mexico, México.

DOF (Diario Oficial de la Federación). 2020. "AGREEMENT specifying the essential activities under the responsibility of the Department of Communications and Transportation due to the health emergency generated by the COVID-19 pandemic." In Spanish. Secretaría de Gobernación, Diario Oficial de la Federación [Online]: https://www.dof.gob.mx/nota_detalle.php?codigo=5591372&fecha=08/04/2020#gsc.tab=0.

Dollfus, O. 2007. *La mondialisation*. Presses de Sciences Po, Paris. France.

ECLAC (Economic Commission for Latin America and the Caribbean). 2019. *Preliminary Overview of the Economies of Latin America and the Caribbean 2019*. Santiago, Chile: United Nations. [Online]: https://www.cepal.org/en/publications/45001-preliminary-overview-economies-latin-america-and-caribbean-2019. Retrieved on 12 October 2021.

ECLAC (Economic Commission for Latin America and the Caribbean). 2020. "The effects of the coronavirus disease (COVID-19) pandemic on international trade and logistics." *COVID-19 Special Report*, No. 6, Santiago, August 6 [Online]: https://www.cepal.org/en/publications/45878-effects-coronavirus-disease-covid-19-pandemic-international-trade-and-logistics. Retrieved on 11 November 2021.

Economist, The. 2016. "A golden opportunity," *The Economist*, November 17 [Online]: https://www.economist.com/the-americas/2016/11/17/a-golden-opportunity. Retrieved on 30 January 2020.

Flores, Z. 2023. "How Mexico's Nuevo León State Landed Tesla's First Plant In Latin America." *Bloomberg Línea*, March 1 [Online]: https://www.bloomberglinea.com/english/how-mexicos-nuevo-leon-state-landed-teslas-first-plant-in-latin-america/.

García, M. 2020a. "Energy and Agriculture, the segments with the best outcomes for GMXT". *T21 Magazine*, July 29, In Spanish [Online]: http://t21.com.mx/ferroviario/2020/07/29/energia-agricola-segmentos-mejor-resultado-gmxt.

García M. 2020b. "Course of the machine face to a virus." *T21 Magazine*, June 12, In Spanish. [Online]: http://t21.com.mx/ferroviario/2020/06/12/rumbo-maquina-ante-virus.

García-Ortega, G., and Jiménez-Sánchez, E. 2021. "Effects of COVID-19 on Road Freight Transport during 2020." In Spanish. *Technical Report No. 628*, Instituto Mexicano del Transporte, San Fandila, Querétaro, México.

IMT (Mexican Institute of Transportation). 2020. *Manual Estadístico del Sector Transporte 2019*. Instituto Mexicano del Transporte, San Fandila, México.

Info-transportaciones. 2021. "Rail traffic closed with a contraction of 9.6% in 2020." AAR [On line]: https://info-transportationes.com.mx/index.php/vias/item/11929-el-trafico-ferroviario-cerro-con-una-contraccion-de-9-6-el-2020-aar. Retrieved on January 11, 2021.

Kasif, Daniel. 2021. "Record Lows for Global Shipping Schedule Reliability." Think Global Logistics, May 16. https://tgl.co/record-lows-for-global-shipping-schedule-reliability/.

Khanna, P. 2020. "All Roads Need Not Lead To China." *NOEMA*, July 13 [Online]: https://www.noemamag.com/all-roads-need-not-lead-to-china/. Retrieved on 10 May 2021.

Kim, J. 2019. "Studies on Supply and Demand Paradox in Shipping Market." *The Journal of Industrial Distribution & Business* 10 (1): 19-27.

Kohli, S., Timelin, B., Fabius, V., and Veranen, S. M. 2020. "How COVID-19 is changing consumer behavior – now and forever." McKinsey & Company, June. [Online]: https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/how%20covid%2019%20is%20changing%20consumer%20behavior%20now%20and%20forever/how-covid-19-is-changing-consumer-behaviornow-and-forever.pdf.

Larios-Gómez, E., Fischer, L., Peñalosa, M., and Ortega-Vivanco, M. 2021. "Purchase behavior in COVID-19: A cross-study in Mexico, Colombia, and Ecuador." *Heliyon* 7 (3): e06468. DOI: 10.1016/j.heliyon.2021.e06468.

Legrain, P. 2020. "The Coronavirus is Killing Globalization as We Know It." *Foreign Policy*, March 12 [On Line]: https://foreignpolicy.com/2020/03/12/coronavirus-killing-globalization-nationalism-protectionism-trump/. Retrieved on 30 March 2021.

Martner, C. 2020. "Globalización, conectividad inter espacial y articulación territorial de los puertos mexicanos." *Revista EURE - Revista de Estudios Urbano Regionales* 46 (139): 233-257. https://www.eure.cl/index.php/eure/article/view/3176/1305.

Martner, C. and A. Pérez. 2020. "Evolución de la carga por los puertos mexicanos: Entre el neoproteccionismo comercial y el COVID-19. Primera Parte." *Gaceta AMANAC* 2 (16): 6-8. https://issuu.com/amanac/docs/gaceta_amanac_abril_2020.

McKibbin, W., and Fernando, R. 2020. "The Global Macroeconomic Impacts of COVID-19: Seven Scenarios." *CAMA Working Paper No. 19/2020*. Centre for Applied Macroeconomic Analysis, Australian National University, Canberra.

Morales, R. 2021. "Canadian Pacific acuerda compra de KCS; creará red ferroviaria que cruzaría América del Norte." *El Economista*, March 21 [Online]: https://www.eleconomista.com.mx/empresas/Canadian-Pacific-acuerda-compra-de-KCS-creara-red-ferroviaria-que-cruzaria-America-del-Norte-20210321-0015.html.

Ng, A. 2020. "Global coordination and political leadership are 'absent' from the world's response to the coronavirus, says former Australian treasurer." *CNBC*, March 13 [Online]: https://www.cnbc.com/2020/03/13/coronavirus-worlds-response-isnt-globally-coordinated.html.

Nomikos, N., and Tsouknidis, D. 2022. "Disentangling demand and supply shocks in the shipping freight market: their impact on shipping investments." *Maritime Policy & Management* 50 (5): 563-581. https://doi.org/10.1080/03088839.2021.2017041.

O'Rourke, L., Beshers, E., and Stock, D. 2015. "Measuring the Impacts of Freight Transportation Improvements on the Economy and Competitiveness." *Report No. FHWA-HOP-15-034*. US Department of Transportation, Federal Highway Administration, Washington, D.C. https://ops.fhwa.dot.gov/publications/fhwahop15034/fhwahop15034.pdf.

Rutner, S.M., and Langley, C.J. 2000. "Logistics Value: Definition, Process and Measurement." *The International Journal of Logistics Managemen* 11 (2): 73-82.

Savy, M. 2016. "Logistics as a political issue." *Transportation Reviews* 36 (4): 413-417. https://doi.org/10.1080/01441647.2016.1182793.

Savy, M. 2017. *Le transport de marchandises: Économie du fret, management logistique, politique des transports*. Lausanne: Presses polytechniques et universitaires romandes.

Shih, W. 2020. "Is It Time to Rethink Globalized Supply Chains?" *MIT Sloan Management Review*, March 19 [Online]: https://sloanreview.mit.edu/article/is-it-time-to-rethink-globalized-supply-chains/. Retrieved on 30 March 2020.

Stankiewicz, K. 2021. "Head of busiest U.S. port urges companies to pick up their cargo more quickly to ease Covid congestion." *CNBC*, March 30 [Online]: https://www.cnbc.com/2021/03/30/head-of-port-of-los-angeles-urges-companies-to-pick-up-cargo-quicker.html.

T21 Magazine. 2020. "COVID-19 continues to affect KCS revenue." *T21 Magazine*, October 20, In Spanish. [Online]: http://t21.com.mx/ferroviario/2020/10/20/Covid-19-continua-afectando-ingresos-kcs.

UN (United Nations). 2020. "World Economic Situation and Prospects 2020." United Nations, Department of Economic and Social Affairs, Economic Analysis, Geneva. https://www.un.org/development/desa/dpad/publication/situacion-y-perspectivas-de-la-economia-mundial-2020-resumen-ejecutivo/.

UNCTAD. 2020. "COVID-19 and Maritime Transport: Impact and responses." UNCTAD/DTL/TLB/INF/2020/1. Geneva: United Nations Conference on Trade and Development. https://unctad.org/system/files/official-document/dtltlbinf2020d1_en.pdf.

WEF (World Economic Forum). 2019. "Outbreak Readiness and Business Impact: Protecting Lives and Livelihoods across the Global Economy." *WEF White Paper*. World Economic Forum,

Geneva. [Online]: http://www3.weforum.org/docs/WEF%20HGHI_Outbreak_Readiness_Business_Impact.pdf.
Whiting, K. 2020. "Coronavirus isn't an outlier, it's part of our interconnected viral age." World Economic Forum, March 4 [Online]: https://www.weforum.org/agenda/2020/03/coronavirus-global-epidemics-health-pandemic-covid-19/.
WHO (World Health Organization). 2020. "Statement on the second meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV)." World Health Organization, January 30 [Online]: https://www.who.int/news/item/30-01-2020-statement-on-the-second-meeting-of-the-international-health-regulations-(2005)-emergency-committee-regarding-the-outbreak-of-novel-coronavirus-(2019-ncov).
Zhao, Yujie, Zhou, H., and Leus, R. 2022. "Recovery from demand disruption: Two-stage financing strategy for a capital-constrained supply chain under uncertainty." *European Journal of Operational Research* 303 (2): 699-718. https://doi.org/10.1016/j.ejor.2022.03.009.