International Journal of *Geo-Information*

MDPI

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Evaluation of Cross-Border Transport Connectivity and Analysis of Spatial Patterns in Latin America

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Abstract: The study of cross-border transport connectivity is significant for the development of regional integration and insight into global patterns. Comprehensive connectivity evaluations are lacking and insufficient attention has been paid to Latin American connectivity, so it is of great practical importance to comprehensively and rationally evaluate Latin American connectivity. In this article, based on the four modes of transport, namely, sea, road, air and railroad, and using the actual trade volume as a comparison, a connectivity evaluation index system with considerable reliability and generalization ability was constructed using the expert scoring method, QAP correlation analysis, QAP regression, and statistics, and the connectivity calculations of Latin America were obtained. Analyzing the connectivity structure of Latin America, it was found that cross-border passenger and cargo transport in the region was dominated by sea transport and supplemented by road and air transport, with railroads used the least. The overall connectivity of Latin America was low, and the overall development was unbalanced, with a strong law of spatial differentiation, which was mainly manifested in the strongest connectivity of the integrated coastal countries, followed by the island countries, and the lowest connectivity of the landlocked countries. Different countries assumed different roles in regional connectivity, which could be categorized into global hub type, local hub type and non-hub type based on the calculations. There was a spatial pattern of decreasing connectivity with distance in typical countries, but the rate of decline was closely related to their geographic location and the role they played in the connectivity network. This study can provide reference and inspiration for regional connectivity evaluation, improvement, and sustainable development.

Keywords: Latin America; cross-border transport connectivity; spatial patterns; evaluation system construction; QAP; sustainability

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Academic Editors: Wolfgang Kainz, Andriani Skopeliti, Anastasia Stratigea, Vassilios Krassanakis and Apostolos Lagarias

Received: 18 September 2024
Revised: 28 December 2024
Accepted: 6 January 2025
Published: 8 January 2025

Citation: Miao, C.; Zhang, Y.; Zhang, X.; Liu, J.; Zhang, S. Evaluation of Cross-Border Transport Connectivity and Analysis of Spatial Patterns in Latin America. *ISPRS Int. J. Geo-Inf.* **2025**, *14*, 22. https://doi.org/10.3390/ijgi14010022

1. Introduction

Regional/inter-country connectivity is an essential condition for regional integration and economic globalization [1], of which transport infrastructure connectivity is an important component. A reasonable evaluation of the capacity of inter-country transport infrastructure connectivity is a reflection of the degree of regional economic integration. It can also provide recommendations for regional cross-border transport construction based on the evaluation results, which can provide enlightenment for regional and global sustainable development.

Connectivity is the ability of nodes in a network to interconnect and spatially interact with other nodes through various means at a given time [2,3]. The broader connectivity emphasizes the importance of availability of transport services and their capabilities within the framework of complex systems theory [4]. Cross-border transport, on the other hand, is defined as infrastructure used for the transport of passengers and goods across the administrative borders of two or more countries [5–11]. According to different modes of transport, it can be divided into sea, road, air and railroad. The level or capacity of spatial interactions (trade in goods, movement of people, etc.) between countries across administrative boundaries through various transport infrastructures can be considered as cross-border transport connectivity (hereinafter referred to as connectivity), which describes the degree of sophistication of the transport network and the ease of interaction between different countries.

At present, there are many results for cross-border transport connectivity. For example, Zong and Pan et al. analyzed the connectivity between global shipping routes and port connectivity based on complex networks [12,13]; Huang et al. studied the impact of "the Silk Road Economic Belt and the 21st-Century Maritime Silk Road" initiative on the containerized maritime transport connectivity of the countries along the route [14]; Zhang et al. analyzed the shipping connectivity characteristics of the "Asian Mediterranean" region from the dimensions of port functions and shipping routes [15]; Kanrak et al. analyzed the connectivity, classification and cluster structure of the cruise shipping network between Asia and Australia [16]; and Wang studied the development of transport corridors in border areas [17]. In addition, scholars such as Allroggen, del Rosal, and Zhang et al. studied shipping and aviation connectivity using gravity modeling, network analysis, and spatial analysis [4,18,19]. The above results mainly focused on a single mode of transport, and lacked comprehensive connectivity evaluation, in-depth study of its impact mechanism, and reliability verification of the evaluation method. At the same time, there is a lack of research on cross-border transport in Latin America, and even less on the study of connectivity in Latin America.

Among the existing studies on connectivity, the research foundation on its relationship with trade is relatively deep, and it can be argued that there is a generally significant positive correlation between connectivity and trade. For example, Calatayud et al. argued that improving connectivity was an increasingly important topic on the international trade and transport policy agenda [20]; Jiao et al. established a gravity model between multiple modes of transport and trade constant prices, and found that increased connectivity between China and the countries along the route positively promoted inter-country trade in goods, and that different modes of transport had different degrees of impact on trade [21]; Canbay, Hoffmann and Saeed et al. found a positive causal relationship between global shipping connectivity and trade, and assessed the extent of the impact of shipping connectivity on trade [22–24]; Oum et al. analyzed the impact of air connectivity on bilateral trade using the gravity model [25]; Bensassi et al. studied the relationship between transport infrastructure and trade using the gravity model [26]; and studies by Li, Matsumoto and Ng et al. also confirmed the positive correlation between connectivity and economy and trade, which were complementary and mutually reinforcing [27–29]. In addition, scholars such as Wang, Zhu, Guchang, Sharma, and Wong also analyzed and explained the linkages between connectivity, economy, and trade using the expert scoring method, modeling, complex networks, and double difference models [30–35].

Therefore, this paper used quantitative methods, based on the four modes of cross-border transport (sea, road, air and rail) and the actual amount of trade as a comparison, combined with expert scoring, statistics, QAP correlation analysis and regression analysis, to construct a comprehensive connectivity evaluation system that was reliable and able to respond to the reality to a considerable extent, and to evaluate the inter-country connectivity of Latin America. After that, the spatial pattern of connectivity in Latin America was analyzed by combining network analysis and visualization. The connectivity evaluation system established by this study is applicable to other regions of the world and has a certain degree of universality; at the same time, the evaluation and analysis of connectivity in Latin America fill a gap in this study in the region and can provide recommendations for improved regional connectivity and integration development.

2. Methods and Data

2.1. Technical Lines of Study

The technical line of research of this paper is shown in Figure 1.

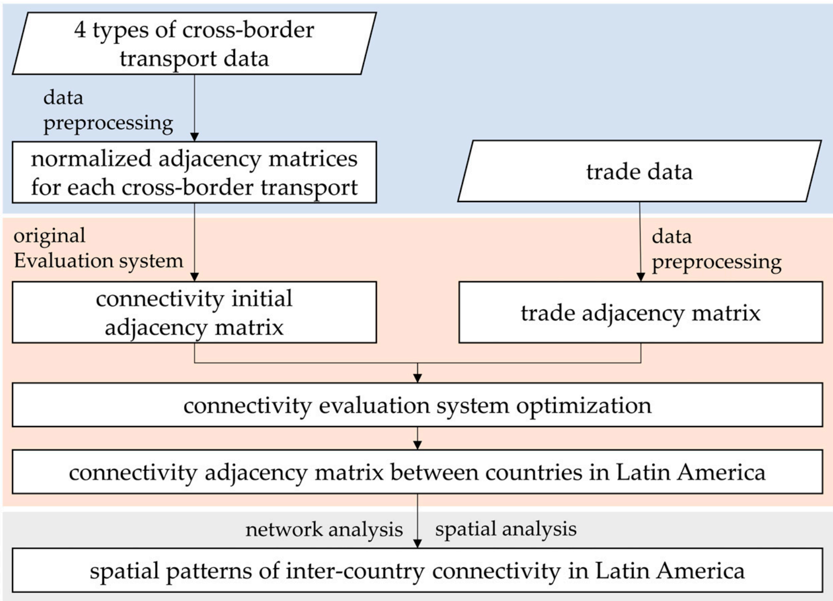

Figure 1. Technical lines of study.

This article used four types of cross-border transport data, namely, cross-border sea, road, air, and rail, for connectivity evaluation. Different cross-border transport types have different connectivity capacities and cannot be directly assigned using the data difference-based assignment method. Therefore, in this paper, the data were divided into two categories to be normalized separately: (i) transport infrastructure connected through physical materials. This form of connectivity is mainly reflected in the interaction between countries through land transport, such as roads, railroads, etc., so the connectivity measurement of this type is mainly based on the number and grade of line facilities. (ii) Transport infrastructure connected by routes. This form of connectivity is mainly reflected in the nodes between ports, airports and other stations, mainly manifested in the routes of transport means. Therefore, the connectivity measurement of sea and air transport is mainly carried out through the number and frequency of routes and flights. The Liner Bilateral Connectivity Index (LBCI) synthesized inter-country sea transport connectivity and could be used directly, while the air transport data were web-crawled to synthesize inter-country route counts and flight frequencies. The normalized adjacency matrices of each cross-border transport among Latin American countries were obtained by preprocessing the above four types of data.

The original connectivity evaluation system was determined by the expert scoring method, and the connectivity initial adjacency matrix of Latin America was calculated based on the normalized adjacency matrices of the above types of cross-border transport. However, the weights of the indicators in the original evaluation system did not fully correspond to the reality of inter-country connectivity in Latin America. Therefore, it was necessary to take the trade adjacency matrix as a comparison, based on the theoretical basis that connectivity and trade should show a strong positive correlation, combined with quantitative calculations to test the reliability of the initial adjacency matrix of connectivity; based on the test results of the original evaluation system of connectivity, it is necessary to optimize in order to obtain more reliable, more realistic results.

The QAP correlation analysis was used to calculate the connectivity initial adjacency matrix and trade adjacency matrix correlation to test the strength of correlation between two adjacency matrices and their significance level, the basic principle of which is shown in Figure 2a. If the calculated correlation coefficients reached a strong correlation ($r \geq 0.6$) and were within the significant level ($p < 0.01$), there was no need to adjust the weights of the indicators for the original evaluation system of connectivity. If it did not reach a strong correlation ($r < 0.6$) or was not within the level of significance ($p \geq 0.01$), the original evaluation system of connectivity needed to be adjusted to the weights of the indicators in order to reach a strong correlation and significance level.

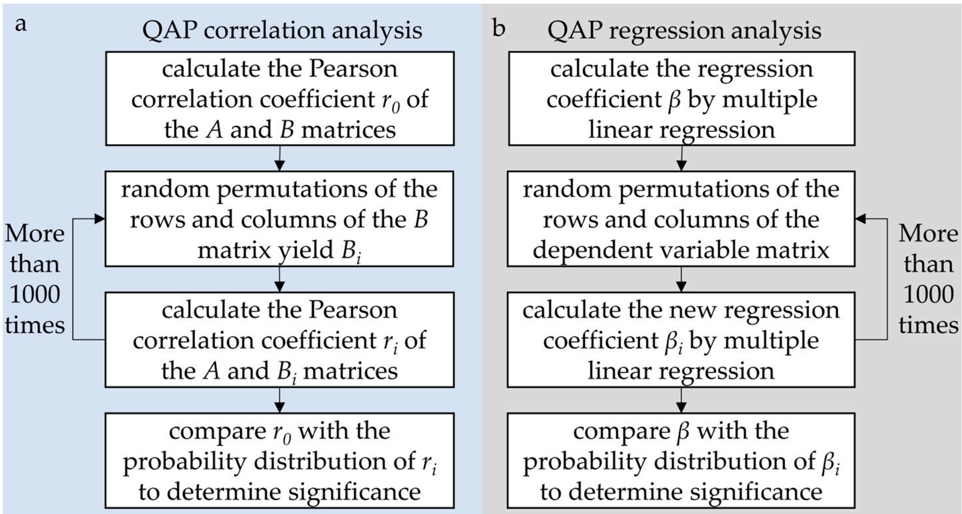

Figure 2. QAP basic principle.

QAP regression analysis was used to analyze and process the independent variable (normalized adjacency matrix of each cross-border transport) and the dependent variable (trade adjacency matrix), the basic principle of which is shown in Figure 2b. Based on the regression results, the impact of different cross-border transport modes on trade (connectivity) was determined, which was used to adjust the weights of the indicators in the original evaluation system of connectivity. Afterwards, the correlation between the adjusted connectivity adjacency matrix and the trade matrix was calculated, and the connectivity evaluation system with the largest r was selected as the optimized connectivity evaluation system.

The optimized connectivity evaluation system was used to calculate the connectivity among Latin American countries, and the spatial pattern of connectivity among Latin American countries was analyzed by combining network analysis methods and visualization tools. In this article, the overall spatial pattern of inter-country connectivity in Latin America was analyzed using overall connectivity and visualization; the spatial characteristics of typical country connectivity in Latin America were analyzed using country centrality, country meso-centrality, and individual country connectivity networks.

2.2. Data

2.2.1. Overview of the Study Area

Geographically, Latin America refers to the American region south of the United States, including Mexico, Central America, the Caribbean, and South America. Latin America has a vast territory, varied topography and landscape, and rich natural resources [36], but the economic development among countries is unbalanced, and the transport structure and level show large differences. This article evaluated the connectivity among 33 sovereign countries in Latin America and analyzed their spatial patterns. Based on the land and sea attributes of the Latin American countries, they were classified into three types: integrated, island, and landlocked. Integrated countries were defined as those connected to the continent and possessing a functional coastline; island countries were defined as those not connected to the continent and primarily consisting of islands; and landlocked countries were defined as those connected to the mainland but lacking a coastline. The names of Latin American countries, the types to which they belong and the corresponding ISO codes are shown in Table 1.

Table 1. Types of Latin American countries and their ISO codes.

Country	Code	Type	Country	Code	Type
Argentina	ARG	Integrated	Honduras	HND	Integrated
Antigua and Barbuda	ATG	Island	Haiti	HTI	Island
Bahamas	BHS	Island	Jamaica	JAM	Island
Belize	BLZ	Integrated	Saint Kitts and Nevis	KNA	Island
Bolivia	BOL	Landlocked	Saint Lucia	LCA	Island
Brazil	BRA	Integrated	Mexico	MEX	Integrated
Barbados	BRB	Island	Nicaragua	NIC	Integrated
Chile	CHL	Integrated	Panama	PAN	Integrated
Colombia	COL	Integrated	Peru	PER	Integrated
Costa Rica	CRI	Integrated	Paraguay	PRY	Landlocked
Cuba	CUB	Island	El Salvador	SLV	Integrated
Dominica	DMA	Island	Suriname	SUR	Integrated
Dominican	DOM	Island	Trinidad and Tobago	TTO	Island
Ecuador	ECU	Integrated	Uruguay	URY	Integrated
Grenada	GRD	Island	Saint Vincent and the Grenadines	VCT	Island
Guatemala	GTM	Integrated	Venezuela	VEN	Integrated
Guyana	GUY	Integrated			

2.2.2. Data Sources

This paper used cross-border sea, air, road, and railroad data and trade data among Latin American countries. The sources of the data and relevant information are presented in Table 2.

Table 2. Data sources and data information.

Data Classification	Data Sources	URL	Corresponding Time
sea	United Nations Conference on Trade and Development	https://unctad.org/ (accessed on 7 May 2024)	A.D.2020
road	natural earth	https://www.naturalearthdata.com/ (accessed on 12 May 2024)	A.D.2020
railroad	natural earth	https://www.naturalearthdata.com/ (accessed on 12 May 2024)	A.D.2020
air	VariFlight Map	https://map.variflight.com/ (accessed on 10 May 2024)	A.D.2020
trade	UN Comtrade	https://comtrade.un.org/ (accessed on 17 May 2024)	A.D.2020

Of these, cross-border roads and railroads were last updated in 2020, so all other data were queried and filtered according to 2020. Regarding sea transport data, the United

Nations Conference on Trade and Development (UNCTAD) database includes the LBCI. The LBCI is based on a combination of variables related to the number of trans-shipments, direct connections, public connections and the size of the largest vessel on the smallest route, and reflects the level of connectivity in the transport of goods by sea between countries.

2.2.3. Data Preprocessing

Using the attribute information contained in cross-border roads and railroads, cross-border roads and railroads were screened with the restriction of crossing the border line, and the cross-border road and railroad adjacency matrix between Latin American countries was constructed. For sea transport, the temporal resolution of the LBCI was quarterly, using 2020 data, filtered and averaged to obtain the sea transport adjacency matrix between Latin American countries. The air transport data mainly included the number of routes and the number of flights, and the air transport adjacency matrix between Latin American countries was obtained by crawling the data. The above adjacency matrices for sea, road, rail, and air transport were normalized and used as inputs for the connectivity calculations below using the expert scoring method. The trade adjacency matrix, on the other hand, serves as a comparison for the accuracy of the connectivity adjacency matrix. The data preprocessing steps are shown in Figure 3.

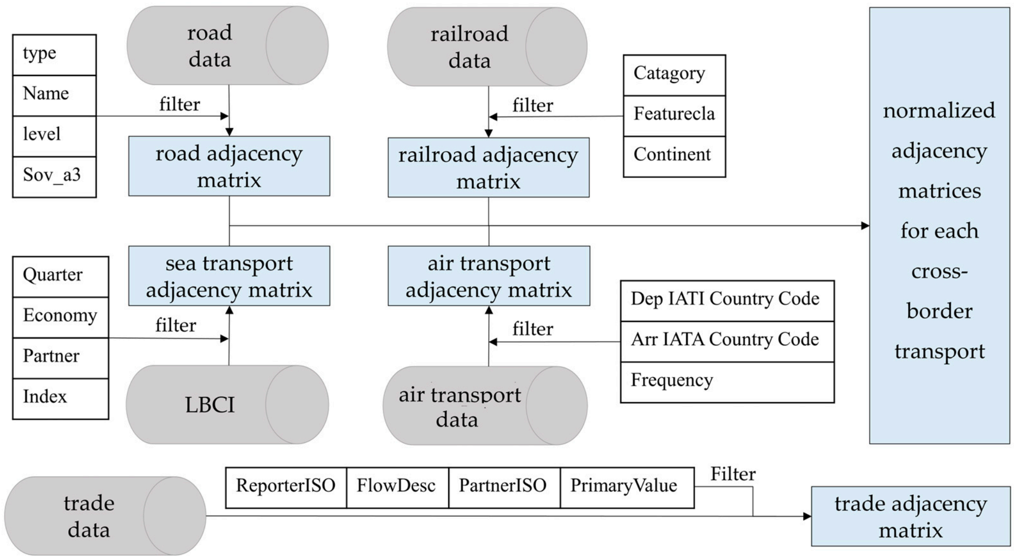

Figure 3. Data preprocessing.

3. Connectivity Evaluation System Construction

3.1. Original Evaluation System

The different indicators in the connectivity evaluation system could not directly adopt the assignment method based on data differences, which required judgment based on certain experience and cognition. Wang et al. [30] used the expert scoring method to assign weights for the connectivity evaluation indicators when evaluating the infrastructure connectivity of China–Silk Road countries. The experts came from the subject group of the third-party assessment report on the progress of the construction of the Silk Road Economic Belt and the 21st Century Maritime Silk Road; the indicators' weights had a certain authority and the calculation results were empirically verified in the analysis section. So, using this evaluation system for inter-country connectivity evaluation had a certain degree of reliability. Therefore, this paper referred to the connectivity evaluation system used by Wang et al. [30] to establish the original evaluation system for inter-country connectivity in Latin America, as shown in Table 3.

Table 3. Original evaluation system for inter-country connectivity in Latin America.

Connectivity Type	Score	Indicator	Score	Meaning
sea	35	LBCI	35	LBCI
railroad	29	Infrastructure connectivity	29	Number of infrastructures
road	18	Infrastructure connectivity	18	number of arterial road connections
air	18	direct route	14	number of routes
		frequency of flights	4	frequency of flights

Based on the normalized adjacency matrix of each cross-border transport, the connectivity initial adjacency matrix of Latin America was calculated using the weights of indicators from the original evaluation system of connectivity, i.e., the connectivity network, as shown in Table 4; using the trade data, the trade adjacency matrix among Latin American countries was screened and sorted out, i.e., the trade network, as shown in Table 5.

Table 4. Connectivity initial adjacency matrix among Latin American countries (2020).

	ARG	ATG	BHS	···	URY	VCT	VEN
ARG	0	13.61	22.45	···	42.61	14.06	14.51
ATG	13.61	0	13.61	···	13.61	14.64	14.73
BHS	22.45	13.61	0	···	22.28	14.02	14.66
⋮	⋮	⋮	⋮	0	⋮	⋮	⋮
URY	42.61	13.61	22.28	···	0	14.06	14.50
VCT	14.06	14.64	14.02	···	14.06+	0	20.41
VEN	14.51	14.73	14.66	···	14.50	20.41	0

Table 5. Trade adjacency matrix among Latin American countries (2020) (US$).

	ARG	ATG	BHS	···	URY	VCT	VEN
ARG	0	629 156	26 972 271	···	1 405 156 415	101 216	110 243 068
ATG	629 156	0	170 100	···	3 249	4 151 004	5 708
BHS	26 972 271	170 100	0	···	699 988	0	650 144
⋮	⋮	⋮	⋮	0	⋮	⋮	⋮
URY	1 405 156 415	3 249	699 988	···	0	0	4 808 796
VCT	101 216	4 151 004	0	···	0	0	0
VEN	110 243 068	5 708	650 144	···	4 808 796	0	0

However, since the realistic connectivity capacity of each transport mode varies in different regions, and although it could reflect the reality of the connectivity in the region to a certain extent, the connectivity in Latin America that was calculated using the original evaluation system was bound to have some bias. Using QAP correlation analysis and setting the number of permutations to 5000, the correlation between the initial adjacency matrix and the trade adjacency matrix for Latin American countries was calculated, and the results are shown in Table 6.

Table 6. Results of QAP correlation analysis between connectivity initial adjacency matrix and trade adjacency matrix among Latin American countries.

Indicator	Pearson Correlation	Significance	Average	Std Dev	N Obs
Value	0.469	<0.001	0.001	0.074	5000

In this result, the Pearson's correlation coefficient r = 0.469 between the connectivity initial adjacency matrix and the trade adjacency matrix proved that there was a moderate positive correlation between the two; the p-value (significance) was less than 0.001, which indicated that the correlation was statistically very significant, and that the event did not occur by chance. The above results proved that the comprehensive evaluation of inter-country connectivity using each cross-border transport as an indicator system was quite reliable. However, its correlation coefficient was $r < 0.6$; therefore, the degree of reflection of this connectivity initial adjacency matrix on the reality of connectivity (trade volume) among countries in Latin America needed to be improved and further optimized.

3.2. Connectivity Evaluation System Optimization

The connectivity evaluation system optimization process is shown in Figure 4.

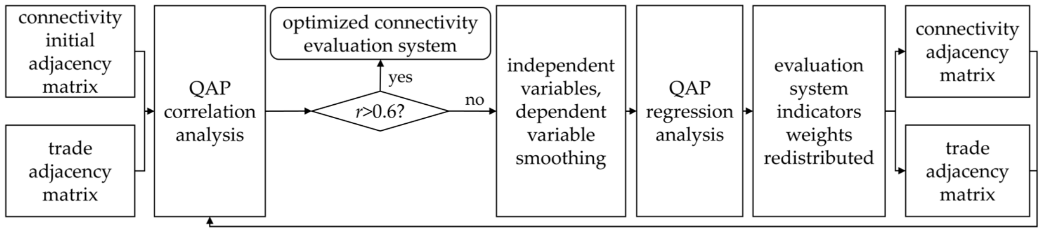

Figure 4. Connectivity evaluation system optimization process.

Regression analysis can measure the degree of influence of different independent variables on the dependent variable, and thus determine the appropriate allocation of weights for different indicators. Therefore, the impact of different modes of transport on trade was measured using the four cross-border transport normalized adjacency matrices as the independent variables and the trade adjacency matrix as the dependent variable. And the determination of the regression method required the analysis and processing of the data of the independent and dependent variables. The data structure analysis of the independent and dependent variables showed that each variable conformed to a normal distribution, but there were outliers (extremely large values, extremely small values, etc.). In order to exclude the effect of outliers, the independent and dependent variables were smoothed using bubble sort and interpolation.

The existence of multicollinearity between variables also affects the selection of regression methods. QAP analysis is a "method of measuring the relationship between relationships" [37], which can effectively solve the problems of multicollinearity and spurious correlation that exist in traditional measures of relational data processing [38]. A number of scholars have already used QAP regression analysis in the fields of transport, trade, tourism, and regional development to conduct research on the influencing factors and driving forces [39–44]. Therefore, in this article, QAP regression analysis was chosen to determine the degree to which the independent variables influence the dependent variable. The results of the QAP regression analysis are shown in Table 7.

Table 7. Results of QAP regression analysis.

Variables	Standardized Coefficient	Significance (p)	Number of Valid Values
sea	0.522	<0.001	1089
railroad	0.037	0.452	1089
road	0.208	<0.001	1089
air	0.202	<0.001	1089

In the above regression results, the larger the standardized coefficients and the stronger the significance (the smaller the p-value), meaning that this mode of cross-border transport had a greater impact on trade, the higher the degree of correlation. Observation of the data showed that sea, road and air transport all had a significant positive impact on trade; however, the degree of impact was different, with sea transport having the greatest impact, followed by road and air transport, while railroads had a non-significant impact on trade. According to the results of the regression analysis, the original evaluation system of connectivity was reallocated with reasonable weights with reference to the regression coefficient, and the allocation results are shown in Table 8.

Table 8. Evaluation system for inter-country connectivity in Latin America.

Connectivity Type	Score	Indicator	Score	Meaning
sea	55	LBCI	55	LBCI
railroad	5	Infrastructure connectivity	5	Number of infrastructures
road	20	Infrastructure connectivity	20	number of arterial road connections
air	20	direct route	16	number of routes
		frequency of flights	4	frequency of flights

Based on the four cross-border transport normalized adjacency matrices, combined with the connectivity evaluation system, the weight-adjusted connectivity adjacency matrix among Latin American countries was calculated, and the results are shown in Table 9.

Table 9. Connectivity adjacency matrix among Latin American countries (2020).

	ARG	ATG	BHS	···	URY	VCT	VEN
ARG	0	21.39	35.27	···	51.99	22.10	22.81
ATG	21.39	0	21.39	···	21.39	23.00	23.14
BHS	35.27	21.39	0	···	35.01	22.03	23.04
⋮	⋮	⋮	⋮	0	⋮	⋮	⋮
URY	51.99	21.39	35.01	···	0	22.09	22.78
VCT	22.10	23.00	22.03	···	22.09	0	31.72
VEN	22.81	23.14	23.04	···	22.78	31.72	0

The correlation coefficients between the above connectivity adjacency matrix and the trade adjacency matrix were calculated using QAP correlation analysis, and the results are shown in Table 10.

Table 10. Results of QAP correlation analysis between connectivity adjacency matrix and trade adjacency matrix among Latin American countries.

Indicator	Pearson Correlation	Significance	Average	Std Dev	N Obs
Value	0.678	<0.001	0.001	0.106	5000

Comparing Table 6 with Table 10, it could be seen that after weight adjustment, the correlation between the connectivity adjacency matrix and trade adjacency matrix was improved from 0.469 to 0.678, and a strong positive correlation level was reached between the two, and the significance was not decreased. Therefore, it could be argued that the adjustment of the indicator weights in the evaluation system of Latin American inter-country connectivity was reasonable and correct, and that the results calculated using this evaluation system were more in line with the reality of inter-country connectivity in Latin America.

The calculated inter-country connectivity results (adjacency matrix) for Latin America were visualized in conjunction with a map to obtain Figure 5, as shown below. The nodes in the figure are the 33 sovereign countries in Latin America, the center of the node is the geometric center of the country vector surface data, and the size of the node is the sum of the connectivity between the different countries and the rest of the countries in the study area; the edges indicate the inter-country connectivity, and the larger the value of the connectivity, the wider the edge.

Figure 5. Visualization of the results of the connectivity evaluation for Latin American countries.

3.3. Comparisons with Existing Studies

At present, there are many studies on transport connectivity based on a single mode of transport (e.g., sea transport, air transport, etc.), and the studies' perspectives are relatively simple. For example, Warnock-Smith et al. analyzed air transport connectivity between the EU and Latin America [45], but the study focused only on air transport connectivity and the development level of transcontinental air transport, which lacked comprehensiveness, and the scale of the study was based on continents and lacked detailed research. In addition, Wilmsmeier, Roach and Seabra et al. studied transport in Latin America focusing only on sea or land transport [46–48]. Meanwhile, Alejandra Saus and Velasco et al. evaluated and analyzed the internal transport of major Latin American cities, with the scale of the study limited to the city level [49,50]. In contrast, this study focused on cross-border transport among countries within the region, which was more complete as it covered the country-region levels at the spatial scale. In addition, this study was based on four modes of cross-border transport, sea, road, air and rail, which made the evaluation system more comprehensive.

Although the connectivity evaluation based on comprehensive indicators is not unique to this study, most of the existing studies have certain shortcomings. For example, Wang et al. constructed an infrastructure connectivity evaluation system by using a variety of cross-border transport data and the expert scoring method; they calculated the connectivity between China and other Silk Road countries and conducted related analyses [30]. However, this method was somewhat subjective and the reliability of the results obtained needed to be strengthened. In contrast, although the original evaluation system of this study was also obtained by the expert scoring method, the verification and correction links were added to enhance the reliability of the method and the credibility of the results. Based on the gravity model, Jiao and Li et al. used trade data to refer to connectivity among countries, and explored the impact of cross-border transport factors on connectivity, but did not really obtain a connectivity index among countries, and thus were unable to carry out further analyses, such as on the spatio-temporal evolution of connectivity [21,51]. The Data Envelopment Analysis (DEA) adopted by Netirith et al. had similar problems, i.e., it only evaluated the mechanisms by which multiple factors, including transport, affect trade [52]. In comparison, this study not only constructed a reliable connectivity evaluation system and explored the connectivity impact mechanism to some extent, but also constructed a connectivity network of Latin American countries and conducted an analysis of the spatial pattern of connectivity.

Above all, there was a lack of regional, cross-country and comprehensive transport connectivity evaluation in Latin America, and this paper constructed a scientific, reliable, comprehensive and expandable evaluation system to compensate for the lack of this aspect.

4. Spatial Pattern Analysis of Connectivity

In this article, network analysis was used to construct indicators measuring different perspectives on connectivity and combined with visual representations to analyze the spatial patterns of connectivity among Latin American countries, with the basic process shown in Figure 6.

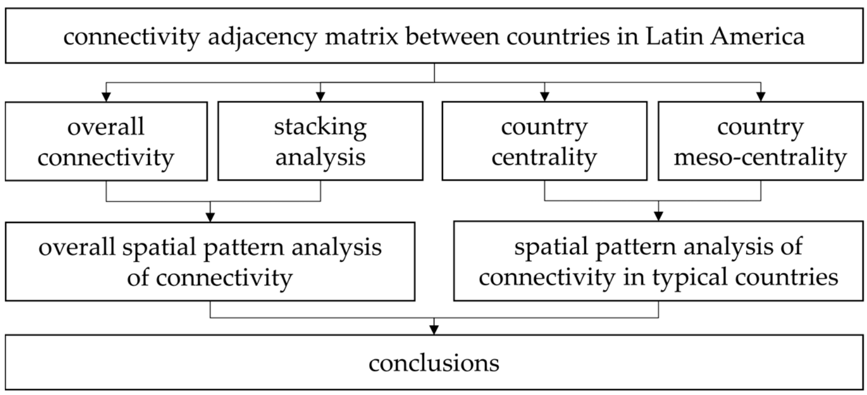

Figure 6. Process for analyzing spatial patterns of connectivity among Latin American countries.

The constructed indicators mainly contained overall connectivity, country centrality, and country meso-centrality:

(i) Overall connectivity

Overall connectivity reflects the overall level of connectivity between countries in the region, and it is solved by multiplying the overall density of the network by the sum of the weights of all edges in the network. Its calculation formula is as follows:

$$D = \frac{\sum_i^N M_i}{N(N-1)} * \sum_i^N Q_{ij} \quad (1)$$

where D denotes overall connectivity, i is a country in the network, M_i is the number of countries connected to country i, N is the total number of countries in the network, and Q_{ij}

is the corresponding inter-country connectivity. The calculated overall connectivity results range from 0 to 100, with higher values meaning a higher level of connectivity among Latin American countries; conversely, the closer to 0, the lower the level of connectivity.

(ii) Country centrality

Country centrality reflects the position of a country in the network, i.e., the higher the country centrality, the more central position the country has in the network; on the contrary, it is at the periphery [53]. Its calculation formula is as follows:

$$C_D(N_i) = \sum_{i=1}^{N} Q_{ij}/(N-1) \tag{2}$$

where $C_D(N_i)$ is country centrality, i is a country in the network, N is the number of countries in the network, Q_{ij} denotes the connectivity between two countries, and $N-1$ denotes the number of edges where country i is connected to all other countries.

(iii) Country meso-centrality

The country meso- centrality is the number of shortest paths passing through node (country) v_i divided by the number of all possible shortest paths in the shortest path from node (country) v_j to node (country) v_k [54,55]. Country meso-centrality reflects the ability of a country to act as the "hub" of a connectivity network. Its calculation formula is as follows:

$$C_B(N_i) = \sum_{j,k \in V} \frac{g_{jk}(i)}{g_{jk}} \tag{3}$$

where $C_B(N_i)$ is the country meso-centrality, g_{jk} denotes the number of shortest paths from node v_j to node v_k, and $g_{jk}(i)$ denotes the number of shortest paths passing through node v_i in the shortest path from node v_j to node v_k.

4.1. Overall Spatial Patterns Analysis

The overall connectivity among Latin American countries has been calculated to be 26.022. As shown by the box plot of connectivity among Latin American countries (Figure 7), the average value of connectivity between a Latin American country and other countries in the region was generally in the range of 20–30, with only a small number of countries having an average value of connectivity with other countries in the region exceeding 30, and individual countries having a connectivity greater than 50. Therefore, it could be argued that the overall connectivity among Latin American countries was low and the level of regional cross-border transport was underdeveloped.

Figure 5 can also represent a visualization of the connectivity network among Latin American countries. As can be seen from the performance of the nodes in Figure 5, the countries with high connectivity in Latin America were mainly those with medium volume (middle level of GDP) and above in the coastal region, such as COL, MEX, PAN, BRA, and DOM, followed by the Pacific Coastal countries. Among the above countries, BRA and MEX were the two largest countries in Latin America, and their level of economic development was also located in the top two; COL and PAN were important transport hubs in the region; other countries such as ARG, CHL, PER and DOM were medium-sized countries in the region, and had a certain degree of influence in the regional economy and politics. And from the side (inter-country connectivity) point of view, there were high levels of connectivity between BRA-ARG (URY), COL-PAN (MEX, DOM), ARG-CHL, CHL-PER, and MEX-PAN.

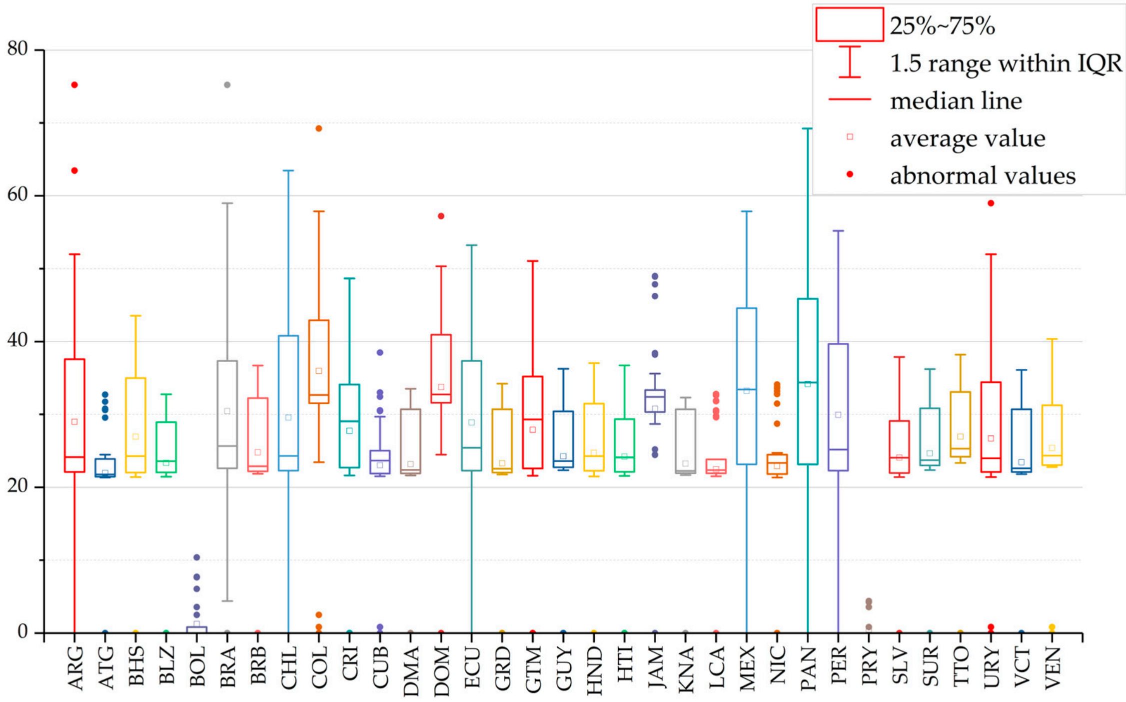

Figure 7. Box plot of connectivity among Latin American countries.

From the above results, it could be seen that the overall connectivity of Latin America was poor and the overall development was unbalanced, which was closely related to the overall physical and geographic characteristics and the level of economic development of the Latin American countries. The complex and varied terrain is the fundamental factor that leads to the low level of connectivity among Latin American countries. The region is bordered by the Atlantic Ocean in the east and the Pacific Ocean in the west; MEX is mainly a highland region, and the Central American peaks are predominantly uneven, which to a certain extent hampers the ease of regional connectivity; the countries of the Caribbean region are mainly island countries, which are convenient for sea transport, but the size of the countries is relatively small; the western part of South America is characterized by the Andes Mountains, and the eastern part of South America is dotted with a number of highland plateaus and plains, of which the best-known one is the Amazonian Plain; the Amazon rainforest and the Brazilian steppe have been shaped by climatic influences, and both mountainous isolation and climatic influences have somewhat hindered the improvement in regional connectivity.

The overall level of economic development in Latin America was low, and the economic growth rate has slowed down in recent years [56], which hindered the improvement in connectivity to a certain extent. The vast majority of Latin American countries are developing countries with a low level of economic development and a fragile economic structure; from 2014 to 2023, the annual growth rate of the Latin American economy was only 0.8%, which was less than half of the annual growth rate of the region in the “Lost Decade” of the 1980s; from 2015 to 2019, GDP per capita growth in Latin America was nearly stagnant. It was especially affected by the COVID-19 pandemic, declining sharply in 2020 [57], and by the end of 2023 had not recovered to the level of 2013–2014. Low, stagnant or even regressive economic growth and increased pressure on government debt were also key factors contributing to the low level of connectivity in Latin America. For example, the Colombian economy, which recovered rapidly after the shock of the epidemic and is growing slowly, has the highest level of connectivity in the region, but still suffers from poor rural roads and the absence of road connections in some cities. Brazil has a fluctuating level of economy, with a high level of connectivity in the region but slow growth. Argentina, whose economy has been on a downward trend in recent years, has a medium to high level of connectivity in the region, but does not have the capacity to invest significant financial support in transport infrastructure development.

The volatility and weak continuity of political systems were important reasons for the low level of connectivity among Latin American countries. Since 2015, many Latin American countries have held general elections, and party rotation and government change have continued to occur, with many of them ending in the ousting of the ruling party. This has led to a lack of continuity in the policies of many countries in Latin America and instability in their relations with neighboring countries, which makes it more difficult to realize long-term strategic investments, such as improvements in the level of transport connectivity. For example, as early as the 20th century, the United States and Latin American countries planned projects such as the Pan-American Highway to promote the construction of regional transport infrastructure. The construction of the Pan-American Highway has improved the road infrastructure of Latin American countries to a considerable extent and accelerated the realization of regional transport integration. However, the progress of the project has been stalled for decades at the Darien Gap (between COL and PAN) due to conflicts of interest, resulting in an imperfect Pan-American Highway [58,59].

Regional transport improvement projects are also being actively implemented within Latin American countries, such as the Iniciativa para la Integración de la Infraestructura Regional Suramericana (IIRSA) and the Proyecto de Integración y Desarrollo de Centroamérica (PM); the main part of these projects includes the construction of transport infrastructure. IIRSA began in 2000 and is now at its peak of project completion, with the construction of highway and railroad facilities being the most important part of the project [60]. PM began in 2001 and focuses on the construction of a highway network in terms of transport, which includes the Pacific Coast Highway and the Atlantic Coast Highway.

In addition, Brazil, Peru, Argentina and other countries have also proposed a number of railroad projects, such as the FIOL railroad in Brazil, the Peruvian railroad, the renovation of the San Martin Freight Railroad in Argentina, and the Two Oceans Railway. Although these projects are mainly domestic, small regional connectivity projects and lack intercontinental-scale connectivity, they can still make positive contributions to the enhancement of connectivity and regional integration in Latin America. At present, 22 countries in Latin America have signed cooperation documents with China to jointly build the Silk Road Economic Belt and the 21st Century Maritime Silk Road; the two sides will certainly continue to strengthen cooperation in infrastructure construction, which will help to further make up for the shortcomings of intercontinental connectivity and promote the integration of transport in Latin America, together with other agreements and projects [61].

4.2. Spatial Pattern Analysis of Typical Countries

Country centrality and country meso-centrality were calculated for Latin America, and the results are shown in Table 11.

As shown in Table 11, integrated countries showed the strongest connectivity with other countries, followed by island countries and finally landlocked countries. This was closely linked to the status of sea transport in international trade.

Based on the above results, the countries in Latin America were classified into three types: global hub type (country centrality > 35.000 and country meso-centrality = 1), local hub type (35.000 $\geq$ country centrality > 29.000 and country meso-centrality > 0.5) and non-hub type (country centrality < 29.000 or country meso-centrality < 0.5); the results are shown in Table 12.

Table 11. Country centrality, meso-centrality and its types in Latin America.

Country	Type	Country Centrality	Country Meso-Centrality	Country	Type	Country Centrality	Country Meso-Centrality
COL	Integrated	37.096	1.000	HND	Integrated	25.509	0.000
PAN	Integrated	35.262	1.000	SUR	Integrated	25.440	0.000
DOM	Island	34.805	0.000	GUY	Integrated	25.002	0.000
MEX	Integrated	34.291	0.000	HTI	Island	24.958	0.000
JAM	Island	31.739	0.000	SLV	Integrated	24.836	0.000
BRA	Integrated	31.389	1.000	VCT	Island	24.160	0.000
PER	Integrated	30.885	1.000	BLZ	Integrated	24.079	0.000
CHL	Integrated	30.496	1.000	GRD	Island	24.019	0.000
ARG	Integrated	29.887	1.000	KNA	Island	23.969	0.000
ECU	Integrated	29.797	0.419	DMA	Island	23.890	0.000
GTM	Integrated	28.755	0.000	CUB	Island	23.742	0.419
CRI	Integrated	28.610	0.000	NIC	Integrated	23.601	0.000
BHS	Island	27.795	0.000	LCA	Island	23.177	0.000
TTO	Island	27.786	0.000	ATG	Island	22.660	0.000
URY	Integrated	27.539	0.581	BOL	Landlocked	1.288	0.065
VEN	Integrated	26.172	0.419	PRY	Landlocked	0.511	0.017
BRB	Island	25.569	0.000				

Table 12. Latin American country types.

Type	Countries
global hub type	COL, PAN
local hub type	BRA, PER, CHL, ARG
non-hub type	MEX, DOM, ECU, JAM, GTM, CRI, BHS, TTO, URY, VEN, BRB, HND, SUR, GUY, HTI, SLV, VCT, BLZ, GRD, KNA, DMA, CUB, NIC, LCA, ATG, BOL, PRY

Colombia (global hub type), Brazil (local hub type) and Mexico (non-hub type) were the most representative of these three types of countries, as they had the largest land area and the largest economic volume. The spatial patterns and basic characteristics of their connectivity with other countries in the region will be analyzed below.

4.2.1. Colombia

COL was an important global hub for cross-border transport in the region. COL had the strongest country centrality in the region, which meant that it had the highest level of connectivity with the countries; at the same time, it also had the largest country meso-centrality and played an important role as a "bridge" in the region. COL connectivity with countries in the region was high and relatively homogeneous overall, but there was also some spatial heterogeneity (as shown in Figure 8): COL had the strongest connectivity with its land neighbor PAN, followed by its sea neighbors DOM and MEX, with the overall center of gravity of connectivity to the northwest. COL also had strong connectivity with landlocked neighboring countries such as PER, ECU, and BRA, and the connectivity tended to decline with increasing distance between countries. In addition, the size of the country was an important factor that significantly influenced the strength of its connectivity, e.g., it also maintained a high level of connectivity with countries that were geographically and spatially distant, such as CHL and ARG.

COL is strategically located, bordering VEN and BRA in the east, ECU and PER in the south, the Pacific Ocean in the west, PAN in the northwest and the Caribbean Sea in the north; together with PAN, it constitutes a transport hub between MEX, Central America, South America and the Caribbean Sea area. In addition, COL's GDP had long been the fourth highest in Latin America, which was among the higher levels in the region. This high economic level provided material support for high connectivity, and supported COL's well-established cross-border sea and air transport system. In terms of trade, PAN, MEX, BRA, ECU and other countries were closely connected to COL and had a high level of trade. In terms of exports, PAN was the largest source of COL's trade surplus, and was more dependent on COL for its domestic mineral resources; ECU, PER, BRA and MEX imported large quantities of chemicals and plastic and rubber products from COL. In terms of imports, MEX and BRA were the largest surplus countries for COL in the region, with COL importing large quantities of electromechanical products, transportation equipment, and base metals and products from both countries.

Figure 8. Spatial patterns of connectivity between Colombia and regional countries.

4.2.2. Brazil

BRA was a local hub for regional cross-border transport; in addition to fulfilling its own national cross-border transport needs, it also served as a "bridge" to a certain extent. BRA's country centrality was ranked sixth, representing a high level of regional connectivity; it also had the highest country median centrality, showing that BRA also served as a transit point to a certain extent. Overall, BRA's connectivity with regional countries had strong spatial heterogeneity (as shown in Figure 9): it was strongest with its land neighbors ARG and URY, with the overall center of gravity of connectivity skewed toward the south; the connectivity with other countries in the region decreased sharply with increasing distance; and although country size also affected connectivity between BRA and other countries to some extent, it was not as significant as COL.

Figure 9. Spatial patterns of connectivity between Brazil and regional countries.

BRA is the largest country in Latin America, bordering ten countries in South America. The relatively gentle terrain creates convenient geographic conditions for cross-border land transport; it is east of the Atlantic Ocean, with a coastline of about 7400 km. Economically, BRA had the highest GDP in Latin America. However, after experiencing the 2019–2020 COVID-19 pandemic shock, Brazil's economy fell back to the level of 10 years ago [62,63]. In terms of cross-border transport, BRA had relatively complete sea, air, and road transport systems, which were the basis for its high level of connectivity. After Lula was re-elected as president, he proposed policies to revitalize the economy and planned to invest BRL 1.7 trillion in infrastructure construction, which would help improve BRA's cross-border transport connectivity. In terms of trade, ARG was BRA's largest trading partner in Latin America, and the two countries cooperated closely in transportation equipment and electromechanical products; the port of Santos was BRA's largest port and also URY's trans-shipment port, which made an outstanding contribution to the connectivity of the two countries; CHL relied more on BRA's exports of minerals and electromechanical products; in addition to this, MEX, PAN, BER and COL were also important regional partners of BRA.

4.2.3. Mexico

MEX was a non-hub country for cross-border transport in the region and played a small role as a regional transit country. MEX ranked fourth in terms of country centrality and had a high level of overall connectivity in the region; however, it did not have a national meso-centrality, which indicated that it did not have a "hub" connectivity role in the region. The connectivity between MEX and regional countries also showed spatial heterogeneity (as shown in Figure 10): it was most strongly connected to the neighboring hub countries PAN and COL, followed by the Pacific Coast countries, PER, CHL, and ECU, and other major countries in the South America, showing a strong tendency for the connectivity to decline with increasing distance.

Figure 10. Spatial patterns of connectivity between Mexico and regional countries.

MEX is bordered by the USA in the north, GTM and BLZ in the south, the Gulf of Mexico and the Caribbean Sea in the east, and the Pacific Ocean and the Gulf of California in the west, which makes it an essential place for land transport between North and South America. Economically, MEX was the second largest economy in Latin America, but the COVID-19 pandemic hit MEX's economy hard [64] and it only recovered to pre-pandemic levels by 2022, and then kept a low growth rate. In terms of cross-border transport, MEX had a relatively complete road system as well as more developed sea and air transport systems, which provided the foundation for its cross-border transport connectivity and trade. In terms of trade, BRA and COL were MEX's most important trading partners in the region. Of these, BRA was MEX's largest importer within Latin America in terms of transportation equipment and optical, horological, and medical equipment, while COL was MEX's largest exporter in Latin America in terms of trade in minerals.

5. Conclusions

This article constructed an inter-country connectivity evaluation system with considerable reliability and generalization ability based on various cross-border transport modes and trade data in a combination of methods. On this basis, an assessment of connectivity among the 33 countries of Latin America (2020) was carried out and the spatial patterns of connectivity were analyzed, leading to the following conclusions:

1. Cross-border transport in Latin America was mainly by sea, supplemented by road and air transport, while railroads rarely undertook cross-border transport.

2. Latin America's overall connectivity was low and development was unbalanced, with a strong law of spatial differentiation. The countries with higher connectivity were concentrated in coastal integrated countries of medium size and above, while island and landlocked countries generally had lower connectivity. This feature was closely related to the physical and geographic characteristics, the level of economic development and the stability of the political systems of the different countries.

3. Different countries in Latin America assumed different roles in regional connectivity, which could be categorized into three types: global hub type, local hub type and non-hub type. The countries represented by Colombia were the global hubs of regional cross-border transport, and they served as transit points for regional passenger and goods transport by virtue of their advantageous geographical location, high level of economic development and well-developed cross-border transport systems. Countries represented by Brazil were localized hubs for regional cross-border transport. They generally had a certain size of land area, a high level of economic development in the region and a relatively well-developed cross-border transport system, while undertaking transit tasks for some of the neighboring countries. Countries represented by Mexico did not undertake transit tasks in regional cross-border transport and mainly accomplished cross-border transport in their own countries.

4. Inter-country connectivity in Latin America generally declined with distance, but the rate of decline was closely related to the specific geographic location and the role assumed in the connectivity network. The closer the geographic location was to the regional center, the slower its connectivity declined with distance. And connectivity was less influenced by distance in global hub type countries compared to local hub type and non-hub type countries.

The connectivity evaluation method proposed in this paper has considerable universality and generalization ability, which is applicable in most regions of the world, and can provide references and ideas for other scholars' related research. Meanwhile, the calculation and analysis of connectivity in Latin America in this paper make up for the lack of connectivity studies in the region. But this study also has some limitations: the paper mainly explores connectivity and its spatial pattern among Latin American countries in 2020, and due to the limitation of data updating, it is not yet possible to assess and analyze the performance of connectivity across a longer time frame; the generalization of the connectivity evaluation method in this paper has certain constraints, which require a relatively complete transport infrastructure between the countries in the region, and a certain degree of accessibility of cross-border transport data that can support a reasonable assessment of connectivity. In subsequent studies, further research will be conducted on the performance of inter-Latin American connectivity and its evolutionary mechanisms on broader time scales. We will also attempt to predict future trends in connectivity.

Author Contributions: All authors made valuable contributions to this paper. Conceptualization: Changqi Miao, Xinjia Zhang, Yinbao Zhang and Jianzhong Liu; methodology: Changqi Miao and Shike Zhang; software: Changqi Miao; validation: Changqi Miao, Xinjia Zhang, Yinbao Zhang and Shike Zhang; formal analysis: Xinjia Zhang, Yinbao Zhang and Jianzhong Liu; resources: Changqi Miao, Xinjia Zhang and Shike Zhang; data curation: Changqi Miao, Xinjia Zhang and Yinbao Zhang; writing—original draft preparation: Changqi Miao, Xinjia Zhang and Shike Zhang; writing—review and editing: Changqi Miao, Yinbao Zhang and Jianzhong Liu; visualization: Changqi Miao and Xinjia Zhang. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Social Science Fund of China—"Theory and Method of Geo-Environmental Analysis in the Era of Big Data", under grant number 20&ZD138.

Data Availability Statement: Data are available in a publicly accessible repository.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Gaens, B.; Sinkkonen, V.; Ruokamo, A. Introduction to the Special Issue: Theory and Practice of Connectivity in the Indo-Pacific-Spheres, Logics, and Regional Dynamics. *East Asia* **2023**, *40*, 195–207. [CrossRef] [PubMed]
2. Wang, G.W.Y.; Zeng, Q.H.; Li, K.; Yang, J.L. Port connectivity in a logistic network: The case of Bohai Bay, China. *Transp. Res. Part E-Logist. Transp. Rev.* **2016**, *95*, 341–354. [CrossRef]
3. Suwanwong, T.; Sopadang, A.; Hanaoka, S.; Rodbundith, T. Evaluation of air cargo connectivity and policy in Thailand. *Transp. Policy* **2018**, *72*, 24–33. [CrossRef]
4. Allroggen, F.; Wittman, M.D.; Malina, R. How air transport connects the world—A new metric of air connectivity and its evolution between 1990 and 2012. *Transp. Res. Part E-Logist. Transp. Rev.* **2015**, *80*, 184–201. [CrossRef]
5. Suau-Sanchez, P.; Burghouwt, G. Connectivity levels and the competitive position of Spanish airports and Iberia's network rationalization strategy, 2001–2007. *J. Air Transp. Manag.* **2012**, *18*, 47–53. [CrossRef]
6. Calatayud, A.; Mangan, J.; Palacin, R. Connectivity to international markets: A multi-layered network approach. *J. Transp. Geogr.* **2017**, *61*, 61–71. [CrossRef]
7. Fan, T. Improvements in intra-European inter-city flight connectivity: 1996–2004. *J. Transp. Geogr.* **2006**, *14*, 273–286. [CrossRef]
8. Jarumaneeroj, P.; Lawton, J.B.; Svindland, M. An evolution of the Global Container Shipping Network: Port connectivity and trading community structure (2011–2017). *Marit. Econ. Logist.* **2024**, *26*, 283–306. [CrossRef]
9. Lee, P.T.-W.; Lee, S.-W.; Hu, Z.-H.; Choi, K.-S.; Choi, N.Y.H.; Shin, S.-H. Promoting Korean international trade in the East Sea Economic Rim in the context of the Belt and Road Initiative. *J. Korea Trade* **2018**, *22*, 212–227. [CrossRef]
10. Zhang, Q.; Wang, B.; Xue, D. The Hub Competition in Delivering Air Connectivity between China and Oceania. *Sustainability* **2022**, *14*, 6482. [CrossRef]
11. Cheung, T.K.Y.; Wong, C.W.H.; Zhang, A. The evolution of aviation network: Global airport connectivity index 2006–2016. *Transp. Res. Part E-Logist. Transp. Rev.* **2020**, *133*, 101826. [CrossRef]
12. Zong, K.; Hu, Z. Research on the connectivity of shipping route network based on complex network. *J. Dalian Marit. Univ.* **2017**, *43*, 79–84.
13. Pan, J.; Wang, X. Port connectivity model based on complex network and its application. *J. Shenzhen Univ. Sci. Eng.* **2017**, *34*, 544–550. [CrossRef]
14. Huang, S.; Wang, B. The impact of the Belt and Road Initiative on container shipping connectivity enjoyed by the countries along the route. *J. Navig. China* **2024**, *47*, 97–102, 110.
15. Zhang, S.; Wang, L. A study on shipping connectivity in the Asian Mediterranean. *Acta Geogr. Sin.* **2022**, *77*, 2616–2632.
16. Kanrak, M.; Nguyen, H.-O. An analysis of connectivity, assortativity and cluster structure of the Asian-Australasian cruise shipping network. *Marit. Transp. Res.* **2022**, *3*, 100048. [CrossRef]
17. Wang, Q. Research on Development Strategy of Cross-Border Transport Corridor in Border Areas—A Case of Ruili in Yunnan. Master's Thesis, Chongqing Jiaotong University, Chongqing, China, 2013.
18. del Rosal, I.; Zanon Moura, T.G. The effect of shipping connectivity on seaborne containerised export flows. *Transp. Policy* **2022**, *118*, 143–151. [CrossRef]
19. Zhang, X.; Liu, C.; Peng, Y.; Lu, J. Connectivity-based spatial patterns and factors influencing international container multimodal hubs in China under the Belt and Road initiative. *Transp. Policy* **2023**, *143*, 10–24. [CrossRef]
20. Calatayud, A.; Palacin, R.; Mangan, J.; Jackson, E.; Ruiz-Rua, A. Understanding connectivity to international markets: A systematic review. *Transp. Rev.* **2016**, *36*, 713–736. [CrossRef]
21. Jiao, J.; Ma, W.; Li, H.; Bu, W.; Wang, J. Impact of connectivity on China's international trade: Taking countries along "the Belt and Road" as examples. *Sci. Geogr. Sin.* **2023**, *43*, 629–637.
22. Canbay, S. The analysis of relationships between global shipping networks and foreign trade volumes in developing countries. *Case Stud. Transp. Policy* **2024**, *17*, 101242. [CrossRef]
23. Hoffmann, J.; Saeed, N.; Sodal, S. Liner shipping bilateral connectivity and its impact on South Africa's bilateral trade flows. *Marit. Econ. Logist.* **2020**, *22*, 473–499. [CrossRef]
24. Saeed, N.; Cullinane, K.; Sodal, S. Exploring the relationships between maritime connectivity, international trade and domestic production. *Marit. Policy Manag.* **2021**, *48*, 497–511. [CrossRef]
25. Oum, T.H.; Wu, X.; Wang, K. Impact of air connectivity on bilateral service export and import trade: The case of China. *Transp. Policy* **2024**, *148*, 219–233. [CrossRef]

26. Bensassi, S.; Marquez-Ramos, L.; Martinez-Zarzoso, I.; Suarez-Burguet, C. Relationship between logistics infrastructure and trade: Evidence from Spanish regional exports. *Transp. Res. Part A-Policy Pract.* **2015**, *72*, 47–61. [CrossRef]
27. Li, W.; Bai, X.; Yang, D.; Hou, Y. Maritime connectivity, transport infrastructure expansion and economic growth: A global perspective. *Transp. Res. Part A-Policy Pract.* **2023**, *170*, 103609. [CrossRef]
28. Matsumoto, H.; Domae, K.; O'Connor, K. Business connectivity, air transport and the urban hierarchy: A case study in East Asia. *J. Transp. Geogr.* **2016**, *54*, 132–139. [CrossRef]
29. Ng, A.K.Y.; Jiang, C.; Li, X.; O'Connor, K.; Lee, P.T.-W. A conceptual overview on government initiatives and the transformation of transport and regional systems. *J. Transp. Geogr.* **2018**, *71*, 199–203. [CrossRef]
30. Wang, C.; Chen, P.; Wang, J.; Li, N. Evaluation method of infrastructure interconnection between China and other countries along the Belt and Road and its spatial pattern. *Geogr. Res.* **2020**, *39*, 2685–2704.
31. Zhu, Z.; Zhang, A.; Zhang, Y. Measuring multi-modal connections and connectivity radiations of transport infrastructure in China. *Transp. A-Transp. Sci.* **2019**, *15*, 1762–1790. [CrossRef]
32. Zhu, Z.; Zhang, A.; Zhang, Y.; Huang, Z.; Xu, S. Measuring air connectivity between China and Australia. *J. Transp. Geogr.* **2019**, *74*, 359–370. [CrossRef]
33. Guchang, A.O.; Yuanhua, J.I.A.; Huiling, Z. Research on Connectivity of Regional Road Network Based on the Capacity of Connectivity. *J. Beijing Jiaotong Univ.* **2009**, *33*, 42–46.
34. Sharma, S.; Ram, S. Investigation of Road Network Connectivity and Accessibility in Less Accessible Airport Regions: The Case of India. *Sustainability* **2023**, *15*, 5747. [CrossRef]
35. Wong, J.C.Y. Aviation Connectivity Impacts on Regional Economies in the United States. *Transp. Res. Rec.* **2018**, *2672*, 103–113. [CrossRef]
36. Carey, M. Latin American environmental history: Current trends, interdisciplinary insights, and future directions. *Environ. Hist.* **2009**, *14*, 221–252. [CrossRef]
37. Liu, J. QAP: A Unique Method of Measuring "Relationships" in Relational Data. *Chin. J. Sociol.* **2007**, *4*, 164–174+209. [CrossRef]
38. Chong, Z.; Qin, C. The Trade Network Structure of "One Belt One Road" and its Influence Factors: A Study Based on Analytic Network Process. *Int. Econ. Trade Res.* **2017**, *33*, 16–28. [CrossRef]
39. Byung-Hak, L.; Won, E.S. Impact of National Cultural Networks on Trade Network: QAP Analysis. *J. Int. Trade Commer.* **2021**, *17*, 11–20. [CrossRef]
40. Choi, J.H.; Barnett, G.A.; Chon, B.S. Comparing world city networks: A network analysis of Internet backbone and air transport intercity linkages. *Glob. Netw.-J. Transnatl. Aff.* **2006**, *6*, 81–99. [CrossRef]
41. Chong, Z.; Qin, C.; Pan, S. The Evolution of the Belt and Road Trade Network and Its Determinant Factors. *Emerg. Mark. Financ. Trade* **2019**, *55*, 3166–3177. [CrossRef]
42. Zhang, N.; Zhang, Y.; Chen, H. Spatial Correlation Network Structure of Carbon Emission Efficiency of Railway Transportation in China and Its Influencing Factors. *Sustainability* **2023**, *15*, 9393. [CrossRef]
43. Park, D.; Lee, G.; Kim, T. Intra-destination Travel Behaviors Analyses using Social Network Analysis Method among FITs from China, Japan, and North Americans to Seoul, South Korea. *J. Int. Trade Commer.* **2019**, *15*, 1–16. [CrossRef]
44. Song, J.; Zhu, Y.; Chu, X.; Yang, X. Research on the Vitality of Public Spaces in Tourist Villages through Social Network Analysis: A Case Study of Mochou Village in Hubei, China. *Land* **2024**, *13*, 359. [CrossRef]
45. Warnock-Smith, D.; Christidis, P. European Union-Latin America/Caribbean air transport connectivity and competitiveness in different air policy contexts. *J. Transp. Geogr.* **2021**, *92*, 102994. [CrossRef]
46. Wilmsmeier, G.; Cullinane, K.P.B.; Notteboom, T.; Sanchez, R.J. IAME 2011-contemporary studies on maritime transport in Latin America. *Marit. Policy Manag.* **2012**, *39*, 549–554. [CrossRef]
47. Roach, K.Q.; Kirton, R.M. Assessing the potential for increased and enhanced maritime transportation in Latin America and the Caribbean: A case study of Trinidad and Tobago and Venezuela. *World J. Sci. Technol. Sustain. Dev.* **2011**, *8*, 81–94. [CrossRef]
48. Seabra, F.; Patricio, T.; Bauer, M.M.; Gheller, L.; Saint Martin, J. Transport Infrastructure and Cross Border Connectivity Indices in Border Cities: The Case of Southern Brazil. *J. Lat. Am. Geogr.* **2022**, *21*, 112–126. [CrossRef]
49. Alejandra Saus, M. State of the art about urban development and transport: Reviewing tools for Latin America. *Econ. Soc. Y Territ.* **2023**, *23*, 991–1016. [CrossRef]
50. Velasco, A.; Gerike, R. A composite index for the evaluation of sustainability in Latin American public transport systems. *Transp. Res. Part A-Policy Pract.* **2024**, *179*, 103939. [CrossRef]
51. Li, J.Y.; Yang, Y.; Ji, X. Research on External Trade Effect of Cross-border Transport Corridor Based on Gravity Model: Taking Kunming-Bangkok Expressway as an Example. *J. Kunming Univ. Sci. Technol. (Soc. Sci.)* **2016**, *16*, 72–77. [CrossRef]
52. Netirith, N.; Ji, M. Analysis of the Efficiency of Transport Infrastructure Connectivity and Trade. *Sustainability* **2022**, *14*, 9613. [CrossRef]
53. Vidya, C.T.; Prabheesh, K.P. Implications of COVID-19 Pandemic on the Global Trade Networks. *Emerg. Mark. Financ. Trade* **2020**, *56*, 2408–2421. [CrossRef]

54. Freeman, L.C. A Set of Measures of Centrality Based on Betweenness. *Sociometry* **1977**, *40*, 35–41. [CrossRef]
55. Freeman, L.C. Centrality in social networks conceptual clarification. *Soc. Netw.* **1978**, *1*, 215–239. [CrossRef]
56. Yue, S. Analysis of Factors that Affect the Economic Growth in Developing Countries: A Case Study of Latin America. In Proceedings of the 7th International Conference on Applied Economics and Business (ICAEB), Copenhagen, Denmark, 24–26 August 2023; pp. 243–254.
57. Tejedor-Estupiñán, J.M. Impactos sociales y económicos de la pandemia de la COVID-19 en Latinoamérica. *Rev. Finanz. Y Política Económica* **2020**, *12*, 329–334. [CrossRef]
58. Orozco Cuello, C.; Sanandres Campis, E.; Molinares Guerrero, I. Colombia, Panamá y la Ruta Panamericana: Encuentros y Desencuentros. *Mem. Rev. Digit. Hist. Y Arqueol. Desde Caribe* **2012**, *15*, 101–130. [CrossRef]
59. Li, C. The Experience and Enlightenment of Pan-American Highway Construction. *J. Lat. Am. Stud.* **2019**, *41*, 133–153+158.
60. Kim, H. Analysis on the Characteristics of IIRSA: Focusing on the Construction of Infrastructure. *J. Assoc. Korean Geogr.* **2020**, *9*, 205–222. [CrossRef]
61. Xie, W. An Analysis of China-CELAC Joint Construction of the Belt and Road Initiative. *Pac. J.* **2018**, *26*, 80–90. [CrossRef]
62. Franz, T. Spatial fixes and switching crises in the times of COVID-19: Implications for commodity-producing economies in Latin America. *Can. J. Dev. Stud.-Rev. Can. D Etudes Du Dev.* **2021**, *42*, 109–121. [CrossRef]
63. Artiga-Purcell, J.A.; Chiasson-LeBel, T.; Leiva, F.; Watanabe-Farro, A. Disaster Extractivism: Latin America's Extractive Shock Therapy in the Age of COVID-19. *Lat. Am. Perspect.* **2023**, *50*, 172–192. [CrossRef]
64. Xiong, A. *Latin American Economy in 2023~2024: Recovery Slows Down*; Social Sciences Literature Publishing House: Beijing, China, 2024; pp. 137–151.