

EFFICIENCY EVALUATION OF AIRPORTS  
OPERATIONS IN PERU USING NETWORK  
ANALYSIS

A thesis in  
Aviation Management

By  
Ricardo Jesús Mariño Uribe

Submitted in Partial Fulfillment of the Requirements  
for the Degree of Master of Science

Aviation Management Program  
The Graduate School  
Korea Aerospace University

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This certifies that master's thesis of Ricardo Jesús Mariño Uribe is approved.

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# SUMMARY

The main characteristic of airport networks is their dynamism. The inclusion of a new air route or the insertion or closure of an airport alters the system and can even lead to the collapse of the network. It is for this reason that it is important to develop a Network Analysis, to know its typology, since its characteristics allow to determine the level of service that the system has and allow decision makers to propose strategies that allow them to achieve the efficiency of the system.

However, in South America there is a gap in the analysis of airport networks; only Argentina and Brazil have managed to describe their networks and generate proposals for improvement. For this reason, this study has adopted the airport network of Peru, which has 66 authorized public airports and is in the process of increasing the capacity of its international airports and including new airport infrastructure.

Within the framework of the multiple scenarios generated in this study, one third of the public airports do not have commercial flights, i.e., they are not part of the system. As a result, Peru has a poorly connected network with reduced cohesion and affiliation.

In addition, the contribution of certain airports that connect those located in isolated cities and without other transportation options is observed. But above all, it shows the importance that the insertion of a new international airport achieves by significantly increasing the efficiency of the network.



The conclusions of this study could have important implications for airport planning and could be considered in the preparation of the Civil Aviation Master Plans (CAMP) that the International Civil Aviation Organization (ICAO) urges its member states to develop in order to recognize the contributions of aviation to sustainable development, resulting in the stimulation of employment, trade, tourism and other areas of economic development.

Keywords: Analysis Network, Efficiency, Evaluation, Strategic Plan, Betweenness, Closeness, Degree Centrality.



# TABLE OF CONTENTS

ACKNOWLEDGEMENTS . . . . .	I
SUMMARY . . . . .	III
TABLE OF CONTENTS . . . . .	IX
LIST OF FIGURES . . . . .	X
CHAPTER 1 INTRODUCTION, BACKGROUND AND OBJECTIVES . . . . .	1
1.1 Introduction . . . . .	1
1.2 Research Background . . . . .	3
1.3 Object of research . . . . .	6
1.4 Research Objective . . . . .	6
LIST OF TABLES . . . . .	1
CHAPTER 2 LITERATURE REVIEW . . . . .	8
2.1 Theoretical Framework . . . . .	12
2.2 Conceptual Framework . . . . .	14
2.3 Contribution . . . . .	15
CHAPTER 3 MODEL AND RESEARCH METHODOLOGY . . . . .	16
3.1 Research Problem . . . . .	16
3.2 Research Model . . . . .	16
3.2.1 Definition of Variables . . . . .	17
3.2.1.1 Network Capacity . . . . .	17
3.2.1.2 Network Efficiency . . . . .	18
3.2.1.3 Degree Centrality . . . . .	19
3.2.1.4 Closeness Centrality . . . . .	19

3.2.1.5	Betweenness Centrality . . . . .	20
3.3	Hypothesis . . . . .	21
3.4	Methodology . . . . .	21
3.4.1	Data Collection . . . . .	21
3.4.2	Processing of data and parameters of analysis. . . . .	22
3.4.3	Descriptive Analysis. . . . .	24
3.4.4	Data Visualization . . . . .	27
CHAPTER 4	DATA ANALYSIS . . . . .	28
4.1	Typology of the nodes . . . . .	28
4.2	Network Metrics . . . . .	28
4.3	Outputs . . . . .	31
4.4	Analysis. . . . .	31
4.4.1	Diameter . . . . .	31
4.4.2	Density . . . . .	32
4.4.3	Average Path Length. . . . .	32
4.4.3.1	Betweenness . . . . .	33
4.4.3.2	Closeness . . . . .	34
4.4.4	Clustering Coefficient. . . . .	35
4.4.5	Average Degree . . . . .	35
4.4.6	Modularity. . . . .	36
4.5	Findings. . . . .	36
4.5.1	Analysis 1 . . . . .	36
4.5.2	Analysis 2 . . . . .	38
4.5.3	Analysis 3 . . . . .	44
4.6	Limitations and future researches . . . . .	47

CHAPTER 5	CONCLUSIONS	49
REFERENCES		51
A	List of Nodes and Links for year and analysis	59
B	Public Airfields Authorized for Peruvian CAA	71
C	Software Output	73

# LIST OF FIGURES

3.1	Research Model . . . . .	16
3.2	Degree Centrality and Closeness Centrality Representation . . . . .	20
3.3	Analysis of Peruvian Airport Network.. . . . .	23
3.4	Peruvian Airport Routes in 2019 . . . . .	25
4.5	<i>A1</i> in Network 2019 and 2022 . . . . .	37
4.6	Evolution of the Flights from CUZ in 2019; 2022 and 2026. . . . .	38
4.7	<i>A2</i> in Network 2019; 2022 and 2026 . . . . .	42
4.8	<i>A3</i> in Network 2019; 2022 and 2026 . . . . .	45
C.1	Betweenness Centrality Distribution in 2019 . . . . .	73
C.2	Betweenness Centrality Distribution in 2022 . . . . .	74
C.3	Betweenness Centrality Distribution in 2026 . . . . .	75
C.4	Closeness Centrality Distribution in 2019 . . . . .	76
C.5	Closeness Centrality Distribution in 2022 . . . . .	77
C.6	Closeness Centrality Distribution in 2026 . . . . .	78
C.7	Clustering Coefficient in 2019. . . . .	79
C.8	Clustering Coefficient in 2022. . . . .	80
C.9	Clustering Coefficient in 2026. . . . .	81

# LIST OF TABLES

3.1	Nodes and Links Analyzed . . . . .	24
3.2	Top 10 Airports by Number of Departing Flights (2022) . . . . .	26
4.3	Complex Network Metrics Utilized in this Study . . . . .	29
4.4	Complex Network Metrics . . . . .	31
4.5	Betweenness Centrality in 2019; 2022 and 2026 . . . . .	33
4.6	Closeness Centrality in 2019; 2022 and 2026 . . . . .	34
4.7	Total Triangles According to Clustering Coefficient . . . . .	35
4.8	Comparative of Airport Metrics . . . . .	40
4.9	Variations in the Betweenness Centrality in A2. . . . .	43
4.10	Variations in the Closeness Centrality in A2 . . . . .	44
A.1	Network in 2019, Nodes for A1 . . . . .	59
A.2	Network in 2019, Links for A1 . . . . .	59
A.3	Network in 2019, Nodes for A2 . . . . .	60
A.4	Network in 2019, Links for A2 . . . . .	61
A.5	Network in 2019, Nodes for A3 . . . . .	62
A.6	Network in 2019, Links for A3 . . . . .	62
A.7	Network in 2022, Nodes for A1 . . . . .	63
A.8	Network in 2022, Links for A1 . . . . .	64
A.9	Network in 2022, Nodes for A2 . . . . .	65
A.10	Network in 2022, Links for A2 . . . . .	66
A.11	Network in 2022, Nodes for A3 . . . . .	66
A.12	Network in 2022, Links for A3 . . . . .	67

A.13	Network in 2026, Nodes for A2	68
A.14	Network in 2026, Links for A2	68
A.15	Network in 2026, Nodes for A3	69
A.16	Network in 2026, Links for A3	70



# CHAPTER 1

## INTRODUCTION, BACKGROUND AND OBJECTIVES

### 1.1 Introduction

In 2019, ICAO, proposes to member states to incorporate the aviation sector in their development plans, proposing to implement initiatives that enable national and global air transport system development. Thus, in the context of national development, it is important to know the topology of the air transport system that are considered complex networks (Guillaumet, 2018; Bagler, 2008; Prabhakar and Anbarasi, 2021; Güner and Keziban Seckin, 2023; Guo et al., 2019; Erdem et al., 2020); in order to define infrastructure investments that improve their capacity and efficiency. Capacity refers to the maximum number of interactions each airport has, measured by the total number of shortest routes passing through it (Motter and Lai, 2002) and Efficiency is based on the transfer of passengers between airports, using the average length of the shortest route as an indicator (Guillaumet, 2018).

Several studies have demonstrated the positive relationship between airport activity and national economic development, through the cities where their airports operate (Debbage Keith, 1999; Green, 2007; Tvetter, 2017), analyzing the results obtained under certain airport management models (Aguirre et al., 2019; Barrantes Caceres, 2012) and above all they conclude on the relevance of air connectivity and its accessibility to move nationally or internationally (Green, 2007; Náchér Ordóñez, 2016). Thus, the air transport system can be analyzed as a network, where nodes represent airports and links represent flights (Trobajo and Carriegos, 2022). Each network presents certain characteristics that describe it (Freeman, 1979) and will allow us to propose actions to improve the system (Wang et al., 2011; Borgatti and Everett, 2006).

Capacity and Efficiency are concepts that are part of ICAO's strategic objectives (In-

ternational Civil Aviation Organization (ICAO), 2019) and will depend on various factors depending on the approach of the analysis (Jacquillat and Odoni, 2018; Urbeltz Isla and Augusto de Oliveira, 2020; Wang et al., 2019). Then, ensuring the capacity and efficiency of the system corresponds to a short-, medium- and long-term process that requires strategic planning to recognize the existing problems that limit it (Rodrigue et al., 2020).

Several studies have analyzed numerous networks in the air transport system either global in scope (Guimerà et al., 2005; Lordan et al., 2014; Nikolaou and Dimitriou, 2021) or country specific (Guillaumet, 2018; Cheung and Gunes, 2012; Hossain and Alam, 2017; Trobajo and Carriegos, 2022; Guida and Maria, 2007; Wang et al., 2011; Lusiantoro and Ciptono, 2012; Erdem et al., 2020). However, to date, the airport network of Peru and many other South American countries have not been analyzed. Furthermore, they have not considered in their analysis new infrastructures that will be inserted or would be inserted into the network and how these would impact its capacity and efficiency.

This type of analysis, with an approach to network capacity and efficiency, will allow decision-makers to propose alternatives to improve the system (new air routes, categorization of airports, among others) or to determine whether the intervention (expansion or modernization) in their existing infrastructure or the construction of a new airport will generate positive impacts for national development.

This study, in addition to adopting a network without previous analysis, presents the system in different scenarios that have not been evaluated in other research and how their results vary and affect the system. It considers all airports that are authorized by the National Civil Aviation Authority and do not have connections with other airports or include new airport infrastructure that will soon be inserted into the network, developing analyses in the past, present and future in order to obtain comparative indicators.

After the analysis carried out, it is concluded that the building of the Cuzco's international

airport brings significant benefits not only to the national network but also to the international network, increasing the efficiency and capacity of the entire system.

The study will address a detailed analysis of Peru's airport network with an approach to its capacity and efficiency. The purpose is to contribute to the body of knowledge in this field and provide a more comprehensive view in the formulation of national strategies. The following chapters will present the findings, analysis and conclusions derived from this research.

The first chapter establishes the rationale for the study, clearly defining the research objectives. The second chapter highlights previous research related to the topic and establishes the conceptual bases that will support the analysis and discussion of the subsequent chapters. The third chapter deepens the core of the research, defines the Research Problem and outlines the questions and challenges that this study seeks to solve. It also presents the research model, identifying the key variables and outlines the methodology. This chapter lays the groundwork for the subsequent analysis and results.

The fourth chapter presents the findings obtained through the detailed study and rigorous analysis of the data collected. This chapter provides a clear and objective view of the results with detailed graphs, tables and analysis to support the conclusions presented in chapter 5. This last chapter summarizes the main findings of the research and relates to the objectives stated in the first chapter.

## **1.2 Research Background**

The main components of the airport system are the airports, the airlines and the users (passengers and cargo) who interact permanently; therefore, the alteration in one or the other -either by an implemented strategy or by an unavoidable circumstance- will impact the other components. This interdependence should represent a need of analysis for decision makers; before, during and after any change in the system.

In October 2019, at its 40th assembly, ICAO (2019) mentions that in order for member states to ensure improvements to their respective air transport systems, they must incorporate the aviation sector within their national development plans, underpinned by sound strategic plans and civil aviation master plans (CAMP).

The CAMP is the document that consolidates various plans aimed at improving, among other things, the capacity and efficiency of the air transportation system. It must be linked to the National Plan to allow for realistic and feasible decision-making.

In other words, wanting to improve an air transport system involves, among other aspects, improving, above all, its capacity and efficiency. However, these are very broad terms in airport management, ranging from the most general to the most specific. General refers to the characteristics of the system as a whole, while specific refers to the characteristics of each of the components and their contribution to the system. It will depend on the focus of what is being evaluated to determine the appropriate indicator.

According to recent reports published by the International Air Transport Association (IATA sustainability & Economics, 2023), May 2023 performance rates are almost the same as pre-pandemic.

However airport throughput is limited by the infrastructure and its operational capabilities. Generating the need for projects to expand capacity such as the construction of new runways. Even demand has grown so much that it is outstripping airport capacity in metropolitan areas (Jacquillat and Odoni, 2018).

CAPA - Centre for Aviation (2022) identified a total of 633 projects (brownfield and greenfield), with a total investment of USD 565.7 billion. There are 202 greenfield projects under construction or planning. The distribution of projects by region shows that Asia-Pacific has the highest number of projects (more than 100) while North America has the lowest number of projects (less than 10); Latin America is in the middle of the table with almost 25

projects.

Peru is currently investing more than USD 2 billion in i) the expansion of the country's main airport (construction of a new terminal, new control tower and second runway); ii) the construction of a new airport that will be the second most important airport due to its location in the country's most touristic city, and; iii) the modernization of concessioned airports that show a potential increase in demand after overcoming the pandemic.

Modern aviation is oriented to achieve maximum efficiency, guaranteeing capacity and safety, so it is necessary to know if the behavior of the components that make up the aviation industry obey a predictable relationship, so that assertive and effective strategies can be proposed.

Therefore, Trinh et al. (2022) and Wang et al. (2011) analyzed the correlation between airport centrality – a feature of network analysis – and regional growth characteristics, enabling policy makers to optimize their decision-making processes regarding sustainable regional development by taking into account mobility and the air transport network, in addition to conventional socioeconomic criteria. On the other hand, in order to develop contingency plans for any airport closure, Lordan et al. (2014) conducted an analysis with the objective of identifying critical airports (those whose isolation would cause the greatest losses in network connectivity).

In summary, the focus on the interdependence of the air transport system (airport-airline-user), analyzed from the perspective of knowing the characteristics of the airport network—focusing attention on the contribution of infrastructure— can be key to incorporate strategies in national plans, in order to ensure capacity and efficiency as proposed by ICAO in its intention to contribute to the 2030 Agenda of the United Nations for Sustainable Development.

However, no studies have been observed where the results of the analysis of their airport

networks have been implemented for the implementation of strategies to ensure Capacity and Efficiency.

We have chosen to analyze Peru's airport network because in South America there is no analysis of airport networks in the region or in a specific country, unlike in other regions. Only Argentina did an analysis of its airport network based on a Network Analysis. In addition, as mentioned above, Peru will include new infrastructure in its network in addition to increasing the capacity of existing airports.

On the other hand, unlike other research, the network analysis carried out in this study considers three scenarios: Before COVID, after COVID (with standardized operations) and with the modified network (after the incorporation of new infrastructure), making a forecast of new flights, which allows the study's validity to be extended.

### **1.3 Object of research**

To analyze Peruvian Airport Network (PAN) using a Capacity and Efficiency approach, in order to evaluate the nature of the interdependence that exists between these attributes, the characteristics of the network and the elements that define it. Based on this understanding, it is possible to propose strategies for national development.

### **1.4 Research Objective**

To analyze PAN in three different scenarios, based not only on the conventional approach adopted by most researchers, but also in the activity of its airports and their location. Address the scenarios in three different temporal situations, in order to evaluate the efficiency before and after the COVID-19 pandemic and projecting the network to 2026.

In addition, it seeks to fill the existing gap in airport network studies in South America; and, based on the results, to propose that the concepts discussed in this study be considered

in the preparation of the Civil Aviation Master Plans (CAMP) that the International Civil Aviation Organization (ICAO) proposes to Member States.

## CHAPTER 2

### LITERATURE REVIEW

There are four elementary considerations for this study: the relationship of an airport to economic development, the complex network analysis, the most important issues for aviation today, and the importance of a strategic plan. Each of these is briefly discussed below:

- Airports: Development Engine

ICAO (2019) urges Member States to recognize the significant contributions of aviation to sustainable development, resulting in the stimulation of employment, trade, tourism and other areas of economic development at national, regional and global levels. Debbage Keith (1999) and Green (2007) found the relationship between airport activity and economic development (population and employment growth); where the latter suggests that, all small cities should not build a large airport and Tveter (2017) studies the impact of airport construction on population and employment growth.

Regional economic development obtains better results with the change in ownership and management; regions with airport concessions have greater economic activity and employment opportunities (Aguirre et al., 2019). Barrantes Caceres (2012) agrees with this benefit generated by airport concessions and highlights, for example, the importance of the concession of the main airport in Peru, since the income generated at this airport allows financing 18 other regional airports. The author also notes the connectivity limitations of isolated localities.

Indeed, Green (2007) suggests connectivity as a key concept when he points out that small cities should have an airport. Náchér Ordóñez (2016) analyzes the probability of choosing an airport to move either domestically or internationally by expressing the importance of the accessibility of populations to airports.



- Network Analysis

The collection of points connected by pairs of lines represents a network, and the pattern of connections between these two components is a crucial aspect of these interactive systems. The particular pattern of interactions can have a great effect on the behavior of the system. Many objects of interest in the physical, biological and social sciences can be thought of as networks (Newman, 2013).

The system (configured by airports and flights originating between these infrastructures) can be analyzed as a network, considering airports as nodes and flights as links (Trobajo and Carriegos, 2022). Several studies have been carried out with the aim of determining the characteristics of the networks of different countries such as Argentina (Guillaumet, 2018), United States (Cheung and Gunes, 2012), Australia (Hossain and Alam, 2017), Spain (Trobajo and Carriegos, 2022), Italy (Guida and Maria, 2007), China (Wang et al., 2011) Indonesia (Lusiantoro and Ciptono, 2012), Turkey (Erdem et al., 2020), there are even studies that analyze the global airport network (worldwide) (Guimerà et al., 2005; Lordan et al., 2014; Nikolaou and Dimitriou, 2021).

To analyze networks we must consider certain characteristics, through which we can better describe the network and, above all, propose measures to improve the system. Freeman (1979) mentions and develops the three best known centrality measures: degree, closeness and betweenness. These measures are adopted in the study of Wang et al. (2011) and Borgatti and Everett (2006), the latter develops a unified framework for the measurement of centrality and points out that “the centrality measures summarize the participation or contribution of a node to the cohesion of the network”.

Trinh et al. (2022) in turn investigates airport network centrality in order to detect key nodes and the interrelation between centrality and regional economy indicators, this conclusion coincides with the study conducted by Wang et al. (2011) who confirms

that the centrality of an airport in a network has important implications in shaping the spatial pattern of economic activities.

On the other hand, Lordan et al. (2014) develops a study, based on comparisons with Bonacich's power centrality, and concludes that most critical airports can be identified with an adaptive strategy and thus be able to elaborate timely responses to airport closures.

Network analysis requires specialized software (Rocha, 2017), various studies have adopted platforms such as: Gephi (Vahidzadeh et al., 2021), Python (Wenxin, 2023), UCINET 6 (Güner and Keziban Seekin, 2023), Networkx (Prabhakar and Anbarasi, 2021), Pajek (Mehra, 2005; Guida and Maria, 2007; Lusiantoro and Ciptono, 2012; Li et al., 2020; Prabhakar and Anbarasi, 2021; Kaya et al., 2022), among others.

- Safety, Security, Capacity y Efficiency

These four concepts are part of ICAO's strategic objectives. The implementation of initiatives in the air transport system must allow improving these aspects; under this approach, sustainable growth will be guaranteed, generating significant socio-economic changes at national, regional and global levels. Infrastructure investments that improve capacity and efficiency support the national development of the State and those that improve safety and security enable the growth of the entire air transport system (International Civil Aviation Organization (ICAO), 2019).

Airport capacity depends on existing infrastructure and air traffic procedures, with weather, takeoff and landing mix, runway configuration, and types of aircraft operating at the airport as alternative variables (Jacquillat and Odoni, 2018). With demand growth, airport capacity is a challenge and landing and takeoff slots are key in airport management (Urbeltz Isla and Augusto de Oliveira, 2020). Additional demand can be met by an alternative airport considering that airport capacity cannot be improved in

a short time (Wang et al., 2019); alternative solutions such as this can be put forward after a timely network analysis.

A reliable demand projection allows finding differences between future demand, existing infrastructure capacity and other necessary resources (personnel, logistics, equipment, among others).

Air transport is a safe mode of transportation (Button et al., 2004). It is the priority of aviation aimed at reducing fatalities, risk of fatalities associated with accidents or protection against unlawful interference. The definition of safety is purely associated with the term risk and its acceptable levels to determine between a safe or unsafe state, thought of as the combination of probability and severity of harm (Arblaster, 2018).

- Strategic Plan

Since 2019, ICAO member states have been working on incorporating the aviation sector into their respective national development plans, supported by strategic plans and civil aviation master plans (CAMP) (ICAO, 2019). This target set is in line with the aviation industry's intention to contribute to the United Nations 2030 Agenda for Sustainable Development. Gomes Teixeira and Canciglieri Junior (2019) present a Strategic Planning method for the Integration of Sustainability in the Product Development Process in different industries.

*"Strategic planning recognizes that a problem exists, . . . , and develops corrective policies and strategies"* (Rodrigue et al., 2020); that, in general, the solutions adopted in transportation planning tend to be more precise and specific than policy guidelines. In this context, if what is sought is to generate strategic plans or master plans, the characteristics of airport networks are key to optimize processes or generate contingency plans (Trinh et al., 2022; Wang et al., 2011; Lordan et al., 2014).

Green (2007) in turn, considers the governance structure important in the political economy of airports and suggests that, because the benefits of airports are diffused throughout the community, airport policy might be better made at the regional rather than local level. It is important to distinguish between public and private airports, as Bollinger (1946) and Díaz Olariaga (2019) agree on the importance of management style according to the type of administration and the importance of generating profitability and efficiency.

In fact, nowadays, profitability and efficiency have been added as an objective of the operator, which motivates airports to compete with each other, having to develop competitive strategies (Forsyth et al., 2011); such as the implementation of certain business areas in their administration (airport commercial development, airport marketing and corporate strategy) (Díaz Olariaga, 2019). This is closely related to achieving high levels of capacity and efficiency in its operation.

## **2.1 Theoretical Framework**

Debbage Keith (1999); Green (2007); Tveter (2017) argued that population and/or employment growth is due to airport activity; therefore, building an airport in small cities will generate economic development. However, its accessibility is also key and even more important to define the importance of the airport for the populations, from the perspective of allowing them to move either nationally or internationally (Nácher Ordóñez, 2016).

Another relevant aspect that ensures better results is the change of ownership for the management of the airports (Díaz Olariaga, 2019). Aguirre et al. (2019) and Barrantes Caceres (2012) agree that regions with airport concessions present greater economic activity and employment opportunities.

All these theories conclude on the positive impact of building an airport depending on

the management and its accessibility.

On the other hand, studies to improve the capacity of an airport conclude in solutions such as: (i) optimizing slots (Urbeltz Isla and Augusto de Oliveira, 2020; Jacquillat and Odoni, 2018), (ii) generating digital twins in BIM (Building Information Modelling) (Pereira Oliveira Patricia, 2020), (iii) setting operating slots or optimizing air traffic procedures (Jacquillat and Odoni, 2018), to which Cook et al. (2015) considers them within the micro-scale analysis; and, proposing solutions for all airports in a system at a national, regional or even global level, is considered as a macro-scale analysis.

Regarding macro-scale analysis, Mallick et al. (2022) points out that the airport network has a significant impact on how a nation or country develops, agreeing with the conclusion of Saleena et al. (2018) on the importance of knowing the network characteristics to revive the economy. This conclusion is based on the existence of a strong relationship between the centrality of an airport network and the economy (Trinh et al., 2022; Wang et al., 2011).

The use of complex network theories enables the understanding of their characteristics and helps to know their behavior (Güner and Keziban Seckin, 2023; Wenxin, 2023) allowing “policymakers” to optimize their decision making processes in sustainable regional development (Trinh et al., 2022; Güner and Keziban Seckin, 2023).

Therefore, it can be concluded that making strategic decisions based on the analysis of the airport system of a country or continent contributes to its development and the growth of its aviation industry. These strategic decisions are generally the responsibility of the public sector of each country, where the planning process identifies the problem and seeks options for solutions (Rodrigue et al., 2020).

In 2019 ICAO provided a guidance text for national aviation planning, which has not been approved and/or updated to date, which contains guidelines on the structure and main components of national CAMPs. However, it is noted that this document does not propose

a methodological framework or tools for the preparation of the Infrastructure Plan, where Capacity and Efficiency are also addressed from the air navigation approach; mentioning: *“With the increase in airspace capacity, there is an urgent need to increase airport capacity”* International Civil Aviation Organization (ICAO) (2019).

In summary, it was mentioned that the national development of the State is linked to infrastructure investments that improve Capacity and Efficiency. However, the studies that have been carried out on network analysis determine the topology and its main characteristics of the system, without giving it a focus on interrelationships or actions that can improve Capacity and Efficiency. That is to say, the questions arises: How can I, from a network analysis, propose improvements to enhance Capacity and Efficiency? What is the relationship between Capacity, Efficiency and Centrality measures of a given network?

## **2.2 Conceptual Framework**

Knowing the behavior of an airport network can enable the creation of strategies that boost the fulfillment of a given country’s national objectives (Mallick et al., 2022) or develop timely responses to events that jeopardize the continuity of service at a given airport (Lordan et al., 2014).

Prabhakar and Anbarasi (2021) manifest that the implementation of complex network models helps in decision making to improve efficiency. They also point out that, for future research, using the information as weights in the network can help us understand which airports can become a Hub to optimize resources or determine the number of passengers traveling to each route in each year and determine the busiest airports. In other words, analyzing the network from an Efficiency and Capacity approach.

## 2.3 Contribution

This research presents a unique contribution to the field of knowledge by addressing three different scenarios in the analysis of an airport network. In addition to the conventional approach adopted by most researchers, in which the network is analyzed by removing the airports without operations, this study includes two more scenarios. The first scenario examines the real situation of the network, including all airports, even those inactive, and the second scenario focuses exclusively on airports within Peru's jurisdiction, excluding those outside Peru.

Additionally, in each scenario this Study analyzes the network before and after the COVID-19 pandemic (2019 and 2022) and projects its efficiency for the year 2026, considering construction works and suggested strategies to improve the efficiency of the airport network in Peru. It generates a total of 8 analysis scenarios that will allow a better interpretation of the network.

This work stands out for its unique approach in South America, since there have been no comprehensive studies on airport networks in this region, with the exception of Argentina and Brazil. It is relevant to note that this limitation highlights the uniqueness of this work, which can fill a gap in the understanding of airport network dynamics in the region.

Furthermore, it is crucial to highlight that the findings of this study could have important implications for airport planning at the international level, as they could be considered in the elaboration of the Civil Aviation Master Plans (CAMP) of the International Civil Aviation Organization (ICAO). This study not only contributes to the understanding of the efficiency of the Peruvian airport network, but may also influence airport practices and policies at the global level.

# CHAPTER 3

## MODEL AND RESEARCH METHODOLOGY

### 3.1 Research Problem

ICAO asks member states to incorporate aviation-related plans in their national plans to guarantee the UN’s sustainability objectives. It is observed that many states or regions do not have an analysis of their airport networks, this puts at risk that the plans that are proposed do not have the necessary foundations to generate strategies in line with the objectives of each country. In this sense, the problem identified in this research is:

*“There is no analysis of airport networks, especially in South America, based on a System Efficiency and Capacity approach”.*

The analysis of airport networks with a focus on Capacity and Efficiency would allow a better understanding of the behavior of an airport system and would help to propose national strategies.

### 3.2 Research Model

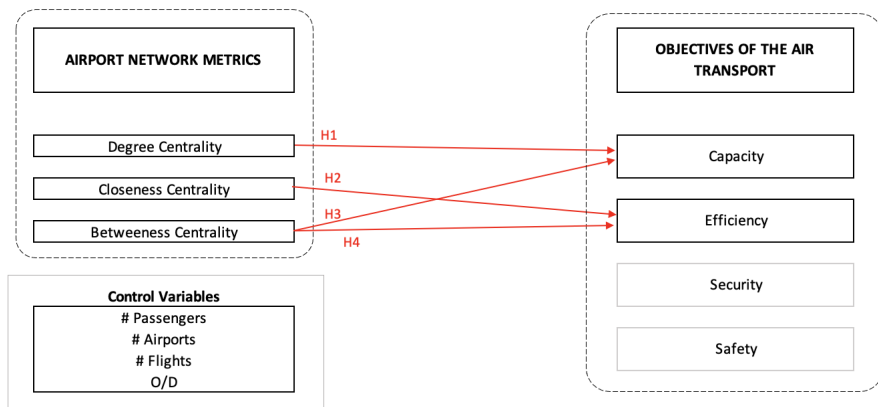


Figure 3.1: Research Model



### 3.2.1 Definition of Variables

For the purposes of this study it is necessary to define the concept of Capacity and Efficiency in terms of an airport network.

As long as Capacity and Efficiency will represent the dependent variables, the characteristics of the network will represent the independent variables:

#### 3.2.1.1 Network Capacity

For a given network, suppose that at each time step one unit of the relevant quantity, which can be information, energy, etc., is exchanged between every pair of nodes and transmitted along the shortest path connecting them. The load at a node is then the total number of shortest paths passing through the node

According to Motter and Lai (2002) the maximum load that the node can handle is the node's capacity. The capacity  $C_j$  of node  $j$  is proportional to its initial load  $L_j$ .

$$C_j = (1 + \alpha)L_j \quad j = 1, 2, 3, \dots, N$$

Where:

$\alpha \geq 0$ : is the *tolerance* parameter.

$L_j$ : is the total number of shortest paths passing through the node, it means "Load".

$N$ : is the initial number of nodes.

If all nodes are operating, the network operates with normality (free-flow state) being  $\alpha \geq 0$ . If a node is removed, in general, the distribution of shortest paths will change; therefore the load on a particular node may change (Motter and Lai, 2002).

Entonces, la capacidad de un sistema está directamente relacionado con la capacidad de

cada nodo que aporta al sistema. Motter and Lai (2002) analiza el escenario en el cual la eliminación de un nodo puede desencadenar cascadas en una red, es decir si el nodo tiene una carga baja, su retirada no causa cambios significativos, pero si tiene una carga alta, puede afectar otros nodos y provocar fallos por sobrecarga.

Por su parte Cumelles et al. (2021) explica cómo los fallos en cascada ocurren cuando el flujo excede la capacidad y desarrolla un algoritmo para gestionar estos fallos evaluando diversas reglas de selección de aeropuertos alternativos para reducir el impacto del fallo en cascada.

### 3.2.1.2 Network Efficiency

Guillaumet (2018) considers that the Efficiency of the Network can be considered as the transfer of passengers from airport to airport, adopting the average shortest path length as an indicator. Where it considers the transfer of passengers as sending information.

In this regard, Latora and Marchiori (2001) defines mathematically the Efficiency in the communication of a Network to be inversely proportional to the shortest distance:

$$\sum_{i \neq j \in D} \frac{1}{SPL_{ij}}$$

Where:

$SPL_{ij}$  = Minimum number of non-stop flights required to connect airport i to airport j. (Morlotti and Redondi, 2021).

Divided by  $N_k(N_k - 1)$  we obtain the average Efficiency.

$$E_D = \frac{1}{N_k(N_k - 1)} \sum_{i \neq j \in D} \frac{1}{SPL_{ij}}$$

Where:

$N_k$  =represents the number of network nodes.

Thus, this definition is associated with the correct use of capacity's network to ensure connectivity.

### 3.2.1.3 Degree Centrality

If we measure the number of nodes connected to a node, we are referring to the degree of centrality; That is, a node will have greater centrality the more nodes are directly connected to it (Song and Yeo, 2017).

According to Nieminen (1974); the degree of centrality will be defined mathematically by the following expression:

$$C_D(i) = \sum_{i=1}^n a(p_i, p_j)$$

Where:

$a(p_i, p_j) = 1$  if and only if  $p_i$  and  $p_j$  are connected by a line 0 otherwise.

### 3.2.1.4 Closeness Centrality

The relative importance of a node considering how close it is to each node in the network is determined by the Closeness Degree. As the number of connecting flights required to reach parts of the network increases, the centrality of closeness decreases Ersoz et al. (2022); Wang et al. (2011). The closeness Centrality of node  $i$  is written as Wang et al. (2011):

$$C_C(i) = \frac{n - 1}{\sum_{j \in D, i \neq j} d_{ij}}$$

Junker et al. (2006) presents a graph (Figure 3.3c) that represents in a simple way the degree of centrality y Closeness Centrality.

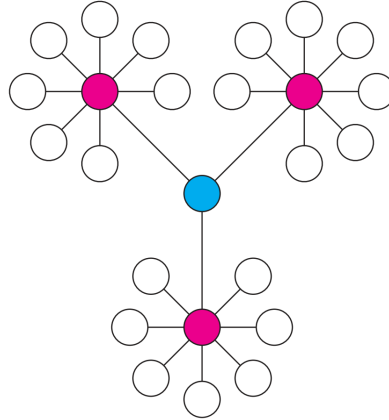


Figure 3.2: Degree Centrality and Closeness Centrality Representation

### 3.2.1.5 Betweenness Centrality

The role that a particular node plays as an intermediary is measured by the Betweenness Centrality (Song and Yeo, 2017). In simple terms, Betweenness Centrality is the sum of the shortest paths through the node to join other nodes (Hatala, 2006; Dang-Pham et al., 2017). Freeman (1977) defines it mathematically with the following expression:

$$C_B(i) = \sum_{j < k}^n \frac{g_{jk}(i)}{g_{jk}}$$

Where:

$g_{jk}$ : is the number of the shortest distance links between node j and node k.

$g_{jk}(i)$ : is the number of times passing between two nodes.

On the other hand, we consider the following as dependent variables: Number of Passengers; Number of Airports; Number of flights and Origin/Destine (O/D).

### **3.3 Hypothesis**

- H1: Is it possible to improve capacity by making changes in my network that substantially modify the Degree Centrality?
- H2: By making improvements that modify the Closeness Centrality, can I improve the efficiency of my network?
- H3: Is it possible to increase capacity by making changes in my network that modify the Betweenness Centrality?
- H4: Is it possible to improve efficiency by making changes in my network that substantially modify the Betweenness Centrality?

### **3.4 Methodology**

#### **3.4.1 Data Collection**

The data corresponds to the Peruvian Civil Aviation Authority (CAA), accessing on all flights performed during pre-COVID and post-COVID season (2019 and 2022, respectively). In addition, for the forecast to 2026, the information contained in the master development plans of main airport has been considered. This data was obtained through requests for access to information that the Peruvian government provides to its citizens within the framework of the Public Information Law.

The information presents all domestic and international destinations, in other words the connections among Peruvian airports and other airports around the world.

### 3.4.2 Processing of data and parameters of analysis

This network analysis considers as temporal scale the 365 days of the year (2019; 2022 and 2026). The decision of using this unit of analysis was founded in the data obtained and ensure the inclusion of low-frequency flights. It is unipartite, it has one kind of nodes and connections, airports and flights respectively (Guillaumet, 2018).

The prerequisite for being deemed part of the network was:

- *For airports*: Have frequent flights or to have operating authorization from the CAA in 2022.
- *For flights*: Regular commercial flights from or to Peru.

Another studies have considered only airports which has frequent flights; in some analysis of this work include airports without frequent flights. In other words, the present study attempts to develop a more detailed analysis considering airports authorized by the Peruvian CAA that serve and do not serve commercial flights, as described below:

- The first analysis, is the real situation of the network, considers domestic airports that are authorized to operate, even though some of them have not had any operations. We assign a value of  $Weight = 0$  which represents no possibility of having non-commercial flights.
- The second analysis, is the conventional approach adopted by most researchers. That is, it only considers the airports that have connections with the flights made and does not include the airports that are part of the system that do not have commercial operations.
- The third analysis, focuses exclusively on airports within Peru, will consider only national airports, in order to determine their air connectivity as a state, and it is in this

analysis that the study will concentrate most of the research to improve their capacity and efficiency as an airport network.

Throughout this work, these analyses will be referred to as follows: Analysis 1 as A1, Analysis 2 as A2, and Analysis 3 as A3. Thus, the resulting network has the following number of connected nodes and links (appendix A):

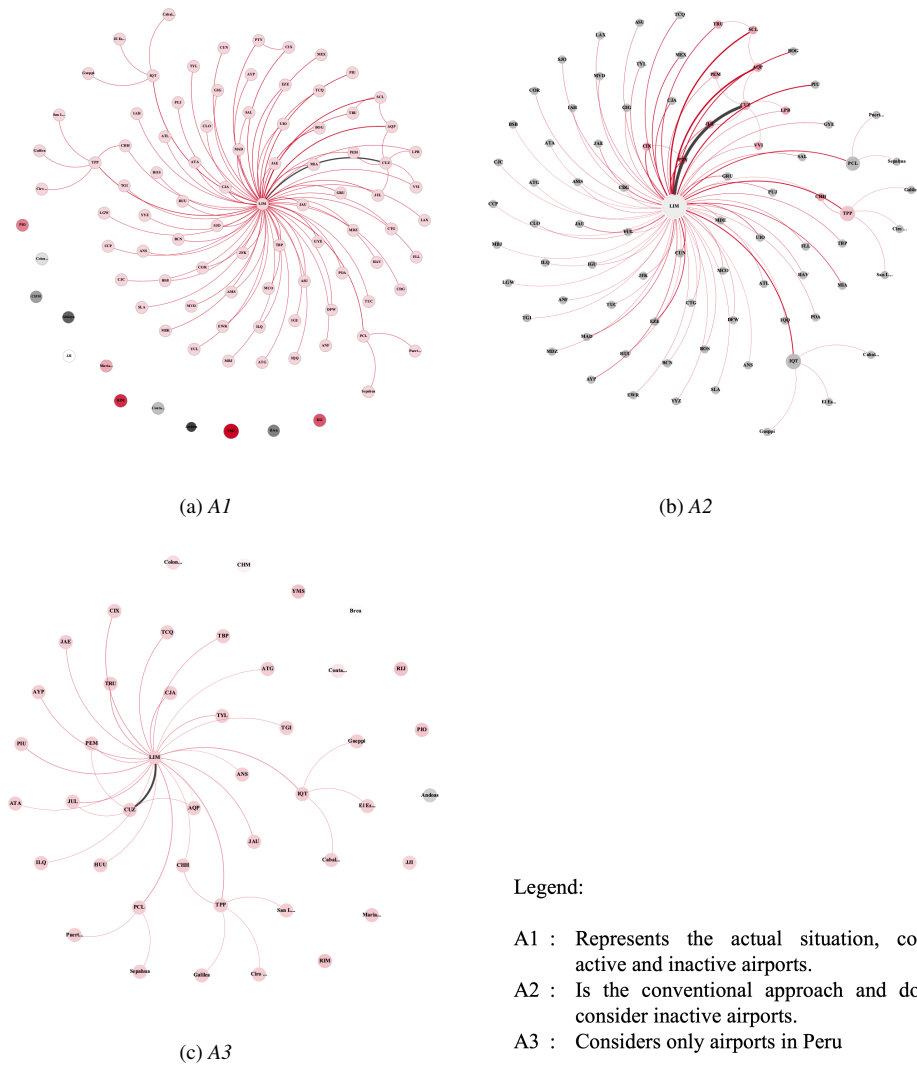


Figure 3.3: Analysis of Peruvian Airport Network.

Table 3.1: Nodes and Links Analyzed

Type of Analysis	2019*		2022*		2026**	
	Nodes	Links	Nodes	Links	Nodes	Links
A1	95	91	87	87	n/a	n/a
A2	83	91	76	87	76	94
A3	44	36	44	38	44	40

(\*): Historical data, provided for CAA

(\*\*): Data from master development plan, provided for CAA

(n/a): not applicable

We consider as an undirected network, because it is considered that the routes are round trips, so each edge corresponds to one trip to go and return (Guillaumet, 2018).

### 3.4.3 Descriptive Analysis

Peru, through its Civil Aviation Authority, has 93 authorized airfields of which 33 are private and 66 are public (see Appendix B). 18 of 66 operate under a concession model (Barrantes Caceres, 2012); 29 are operated by a public entity (CORPAC S.A.); 18 by local or regional governments and 1 by the National Police. Likewise, 36 are defined as aerodromes and 30 as airports, of which 11 are international category airports, with Cusco Airport being the only international airport operated by a public entity and the others through a concession.

In order to decentralize and achieve an integral, harmonious and sustainable development of the country, Peru has established a hierarchy of airport infrastructures based on criteria related to the type of aircraft it can receive, the type of operations it can handle, its location in the national territory or the operation of international flights. Thus, 28 airports have a national category, 10 have a regional category; 8 have a local category and 10 are not yet categorized.

This study analyzes 95 airports in 2019 and 87 in 2022, of which 44 airports are located in Peruvian territory. In 2019 it is observed that 91 routes have operated among the 95 airports



and in 2022 it is observed that 87 routes have operated in the 87 airports analyzed. By 2026 the number of routes will increase to 94. (see table 3.1 and Appendix B)

11 of the 44 airports analyzed are not being connected by commercial flights, which in our case are airports into the Peruvian territory (see Fig. 3.3. An important value in this analysis is the number of authorized but inactive aerodromes; a total of 22 authorized aerodromes with no connectivity are observed in the network, that is, one third of the authorized aerodromes do not have commercial flights.

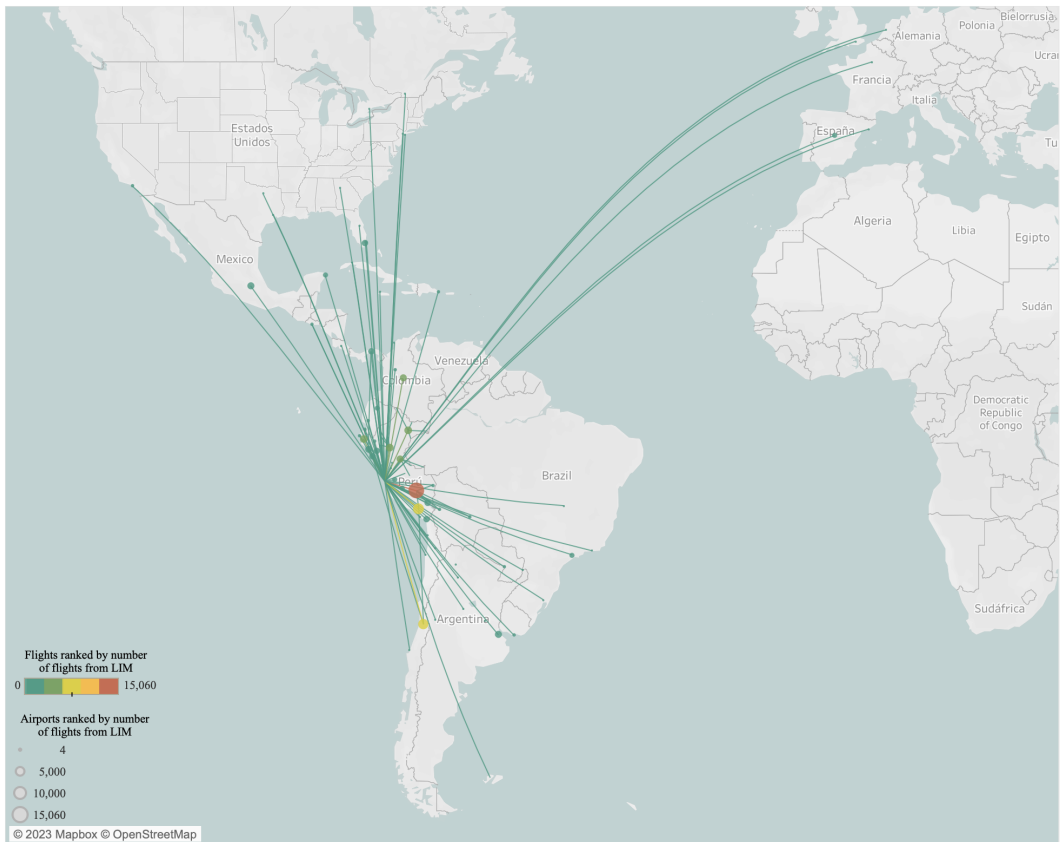


Figure 3.4: Peruvian Airport Routes in 2019

In 2022 the nodes are connected through 71 791 edges; 46 916 national and 24 871 international, in other words airports connected by flights. The International Airport Jorge

Rank	City	IATA Code	Country	No. of aircraft movements	Rank in 2019	No. of air routes
1	Lima	LIM	Peru	137,362	1	65
2	Cuzco	CUZ	Peru	19,958	2	9
3	Arequipa	AQP	Peru	11,110	3	3
4	Piura	PIU	Peru	6,748	5	1
5	Santiago de Chile	SCL	Chile	6,690	4	n/a
6	Tarapoto	TPP	Peru	6,588	7	5
7	Iquitos	IQT	Peru	5,224	6	6
8	Bogota	BOG	Colombia	5,162	8	n/a
9	Trujillo	TRU	Peru	4,968	13	2
10	Pucallpa	PCL	Peru	4,512	9	4

Table 3.2: Top 10 Airports by Number of Departing Flights (2022)

Chavez (LIM) serves to Great Lima, the biggest urban agglomeration of the country, with a population of 10,15 millions of inhabitants (30,1% of the country total), and concentrates 98% of the flights. In the Table 3.2 is shown the top 10 of airports that contributes to the Peruvian Network with high number of flights.

Regarding the number of annual flights, LIM concentrates the largest number of flights (137 362). The route with the highest demand is LIM-CUS, close to 15% of the total flights in Peru corresponds to this route (19 958 flights). The second route is LIM-AQP, close to 8% (11 110 flights). PIU; SCL and TPP contributes to the system with 4.91%; 4.87% and 4.79% respectively.

Furthermore, the Table 3.2 and the Figure 3.1 shows that LIM is the airport with the most air routes (65 routes between domestic and international connections), CUZ have 9 connections, IQT have 6, TPP have 5 air routes (5 domestic connections), PCL has 4 air routes. Additionally, CHH have 2 and the rest of the Peruvian airports have only one air route (connection to LIM).

Thus, IQT and TPP each have approximately 7.69% of the air routes that LIM has. PCL has 6.15%, and CHH has 3.08% of Lima's air routes. Regarding aircraft movements; IQT has 4.12% of the aircraft movements of LIM, TPP has 5.02%, PCL has 3.76%, and CHH has 0.38% of Lima's aircraft movements.

With respect to the frequency of flights, Domestic flights are more common from (Monday to Friday), primarily operated by LATAM, VIVA Air, SKY airlines (domestic airlines), indicating a focus on the national market. Moreover, International flights are distributed as follows: 75% in South America, 11% in North America, 9% in Europe, and 5% in Central America, Oceania, Asia, or Africa. In contrast to domestic flights, the international market displays greater diversity.

#### **3.4.4 Data Visualization**

The information collected has been previously processed in Microsoft Excel, in order to give it the appropriate format for the next processing step.

Gephi was used to build and visualize the network, where each Node representing an airport was identified with the respective IATA code. The Force Atlas and Yifan Hu distribution was applied for the visualization.

The first one makes the graphs more compact, readable, and can show Authorities more in the center than hubs, the second one restricts force calculations to neighboring nodes.

In addition, due to the large volume of data, Tableau has been used to produce graphs or to obtain interpretations of the information contained in the database.

# CHAPTER 4

## DATA ANALYSIS

### 4.1 Typology of the nodes

Guillaumet (2018) considers three typologies of nodes, defined by shared characteristics in their distribution in the network: Central; Intermediate and Peripheral Airports.

The Central Airports are considered Hubs, the great majority of flights depart or arrive from this airports. Its shortcomings will lead to the collapse of the network (Lordan et al., 2014). The Intermediate airports attracts flights because their strategy location (commerce or tourism). If these airports failures could produce paths longer, however, the network will still work properly. Regarding the Peripheral Airports, are only connected with the first one or second one, then its failures have an almost imperceptible impact.

In this regard, the Peruvian airport network in 2022 has one (01) Central Airport, LIM; four (04) Intermediate Airports (IQT, TPP PCL and CUZ) and the remaining airports are considered Peripheral Airports (see Table 3.2 and Figure 4.5b).

### 4.2 Network Metrics

To evaluate the topological properties is use the following complex network metrics: Diameter, Density, Average Path Length, Betweenness, Closeness, Clustering coefficient, Average Degree and Modularity.

Table 4.3: Complex Network Metrics Utilized in this Study

Measurement	Definition												
Network Diameter	The Diameter is the longest network distance between any two nodes in the network (i.e. how far apart are the two farthest nodes in the network). Indicates the average number of transfers required between two airports (Güner and Keziban Seckin, 2023)												
Network Density	Measures how close the graph is to being complete. A complete graph has all possible edges and a density equal to 1. Density shows how much the nodes in a cluster are connected to each other. It is calculated as the percentage of actual connections relative to the maximum possible if all nodes were connected to each other (Hansen et al., 2019).												
	<table border="1"> <thead> <tr> <th>Category</th> <th>Very Low</th> <th>Low</th> <th>Medium</th> <th>High</th> <th>Very High</th> </tr> </thead> <tbody> <tr> <td><b>Value range</b></td> <td>0.00 - 0.19</td> <td>0.20 - 0.39</td> <td>0.40 - 0.59</td> <td>0.60 - 0.79</td> <td>0.80 - 1.00</td> </tr> </tbody> </table>	Category	Very Low	Low	Medium	High	Very High	<b>Value range</b>	0.00 - 0.19	0.20 - 0.39	0.40 - 0.59	0.60 - 0.79	0.80 - 1.00
Category	Very Low	Low	Medium	High	Very High								
<b>Value range</b>	0.00 - 0.19	0.20 - 0.39	0.40 - 0.59	0.60 - 0.79	0.80 - 1.00								
Average Path Length	<p>The average network distance between all pairs of nodes, connected nodes have distance 1 (Brandes, 2001).</p> <ul style="list-style-type: none"> <li>• <i>Betweenness</i>: Measures the frequency with which a node appears on the shortest path between nodes in the network. In other words, it represents the node's contribution to the system as a communication bridge with other nodes (Trobajo and Carriegos, 2022).</li> <li>• <i>Closeness</i>: The average distance from an initial node to all other nodes in the network (Newman, 2005). It considers the shortest paths between airports (Nikolaou and Dimitriou, 2021).</li> </ul>												

– Continued on next page –

Measurement	Definition
Clustering Coefficient	<p>Together with the average value of the shortest path, can indicate a small-world effect. A small-world network generally has a small average path length and a large clustering coefficient (Watts J. and Strogatz H., 1998).</p> <p>It indicates how the nodes are embedded among their neighboring nodes. The average value gives an indication of the clustering of the network. Cluster coefficient for a node is calculated based on the number of triplets of the node.</p>
Average Degree	<p>Degree is the number of connections that a node has. Average Degree is a measure that indicates, on average, how many connections each node in the network has. It provides a general sense of the network's connectivity (Güner and Keziban Seckin, 2023).</p> $\langle k \rangle = \frac{\sum_{i=1}^N k_i}{N}$ <p>Where: <math>k</math> : Average degree; <math>N</math> is the total number of nodes in the network. <math>k_i</math> represents the degree of node <math>i</math>.</p>
Modularity	<p>Algorithm for detecting communities (Vahidzadeh et al., 2021; Guimerà et al., 2005). The strength of division of a network into Modules is determined by this metric (Ji et al., 2015)</p> <p>The following equation is used to measure the modularity (Guimerà et al., 2005):</p> $M = \sum_{s=1}^r \left[ \frac{l_s}{L} - \left( \frac{d_s}{2L} \right)^2 \right]$ <p>Where: <math>r</math> : number of modules; <math>l_s</math> : number of edges between vertices in module <math>s</math>; <math>L</math> : number of edges in the network; <math>d_s</math> sum of the degrees of the vertices in module <math>s</math>.</p>

### 4.3 Outputs

After processing the data (presented in Appendix A), the following results have been obtained:

Table 4.4: Complex Network Metrics

Analysis	Network	Diameter	Density	Average Path Length	Average Clustering Coefficient	Average Degree	Modularity	Communities
A1	2019	4	0.020	2.156	0.651	1.916	0.000	13
	2022	4	0.023	2.214	0.693	2.000	0.000	12
A2	2019	4	0.027	2.156	0.651	2.193	0.000	1
	2022	4	0.031	2.214	0.693	2.289	0.000	1
	2026	4	0.034	2.198	0.764	2.526	0.000	1
A3	2019	4	0.038	2.354	0.513	1.636	0.000	12
	2022	4	0.040	2.437	0.553	1.727	0.000	12
	2026	4	0.042	2.361	0.571	1.818	0.000	12

### 4.4 Analysis

Each of the metrics presented in Table 4.4 is discussed in the following section:

#### 4.4.1 Diameter

In 2019, the found value for the diameter indicator, in *A1*, *A2* and *A3* is equal to 4, which means that one passenger needs to change at most 3 flight to reach from any airport to any other airport (Bagler, 2008; Güner and Keziban Seckin, 2023). The diameter can be defined as the longest of all shortest paths (Hossain and Alam, 2017; Bagler, 2008). According to the Table 4.4, identical values were obtained in 2022 and 2026 network.

A lower diameter is preferred in an ideal airport network, implying more direct flights between airports (Lordan et al., 2014; Güner and Keziban Seckin, 2023).

The degree of connection in a network refers to the Density metric, which is assessed in the next section.

#### **4.4.2 Density**

In *A1*; *A2* and *A3* of 2019 network, the Density indicators are 0.020; 0.027 and 0.038, respectively; it means the network has a *Very Low Density* (see Table 4.3). Therefore, it can be indicated that the network is not very connected.

Similar results have been obtained in *A1*; *A2* and *A3* of 2022 Network, where the values were 0.023; 0.031 and 0.040. This indicates that the 2022 network remains relatively poorly connected.

In line with Hansen et al. (2019), this study is describing the interconnection between the airports of the system, determining a reduced cohesion and membership. Consequently, to improve the efficiency of the network the number or average of existing connections to circulate through the airports should be defined, obtaining these results in the next section.

#### **4.4.3 Average Path Length**

In *A1* of 2019 network, the Average Path Length, which defines the average number of connections that need to be made to reach between any two vertices (Ersoz et al., 2022); presents a value of 2.156. In other words, an average of 2.156 steps are needed to go from one airport to another.

This measure is the same in *A2*. In *A3* the Average Path Length reaches a value equal to 2.354. It means the inconvenience of traveling in the network (Wang et al., 2011), considering the limited frequency and reduced number of airlines that Peru has in domestic transport.

The similar values for each analysis do not express improvements in the network, in other words there are still drawbacks to travel. The same behavior is observed in 2022, a value of



2.214 in 2019 and 2022 and then increase to 2.437. In 2026, the value obtained in A2 is 2.198 and in A3 increased to 2.361.

When analyzing the Average Path Length, it is necessary to study two keys concepts; the Betweenness and Closeness:

#### 4.4.3.1 Betweenness

If we wish to connect two nodes in the network, we may find nodes on the path, the measurement of the frequency with which each node appears on the short path between nodes is the Betweenness centrality.

A high Betweenness Centrality value for a specific airport, represents the capacity to control a significant part of the flow of traffic in the network, by the significant number of nodes connected through it (Trobajo and Carriegos, 2022).

Figure 3.3 show the importance of LIM in the network, a statement corroborated by Table 3.2 which indicates that LIM concentrates 98% of the flights. In other words, if a passenger need to move from a airport to other one needs pass for LIM. Four other airports may have this "bridge airport" status in the Peruvian network: CUZ, IQT, TPP and PCL (see Figures 4.8a and 4.8b).

Table 4.5: Betweenness Centrality in 2019; 2022 and 2026

Airport	A1		A2			A3		
	2019	2022	2019	2022	2026	2019	2022	2026
<b>LIM</b>	0.752231	0.740219	0.990063	0.974955	0.933694	0.523256	0.496124	0.43577
<b>IQT</b>	0.054907	0.079343	0.072267	0.104505	0.108829	0.099668	0.130676	0.143965
<b>TPP</b>	0.054907	0.059918	0.072267	0.078919	0.079820	0.099668	0.099668	0.102436
<b>PCL</b>	0.036834	0.059918	0.048479	0.078919	0.078919	0.067553	0.099668	0.099668
<b>CUZ</b>	0.001144	0.007524	0.001506	0.00991	0.028829	0.001661	0.014396	0.014396
<b>AQP</b>	0.000144	0.000000	0.000151	0.000000	0.000000	0.000000	0.000000	0.000000
<b>SCL</b>	0.000144	0.000274	0.000151	0.00036	0.00036	n/a	n/a	n/a
<b>PTY</b>	0.000000	0.000000	0.000000	0.000000	0.00018	n/a	n/a	n/a
<b>others</b>	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Figures C.1; C.2 and C.3 (see in Appendix C) show the Betweenness Distribution of nodes based in their values and quantity of nodes.

#### 4.4.3.2 Closeness

Closeness Centrality quantifies how close a node is to all other nodes in a network. A highly central node has shorter distances to others (Ji et al., 2015). It reflects the time needed to sequentially transmit information from a node to all others (Newman, 2005).

The number of connecting flights determines its value. As the connections to reach a network node increase, the value of Closeness Centrality decreases (Ersoz et al., 2022).

Most of the airports in Peru have centrality values between 0.4 and 0.5 (see Table 4.6). We observe that LIM has a Centrality value greater than 0.76, confirming that was previously mentioned regarding its importance in the network.

Table 4.6: Closeness Centrality in 2019; 2022 and 2026

Airport	A1		A2			A3		
	2019	2022	2019	2022	2026	2019	2022	2026
<b>LIM</b>	0.911111	0.882353	0.911111	0.882353	0.882353	0.800000	0.761905	0.761905
<b>IQT</b>	0.49697	0.500000	0.49697	0.500000	0.528169	0.492308	0.500000	0.571429
<b>TPP</b>	0.500000	0.493421	0.500000	0.493421	0.510204	0.500000	0.484848	0.524590
<b>PCL</b>	0.491018	0.490196	0.491018	0.490196	0.506757	0.477612	0.477612	0.516129
<b>CUZ</b>	0.493976	0.510204	0.493976	0.510204	0.535714	0.470588	0.500000	0.500000
<b>CHH</b>	0.491018	0.483871	0.491018	0.483871	0.483871	0.4677612	0.463768	0.463768
<b>AQP</b>	0.485207	0.477707	0.485207	0.477707	0.477707	0.457143	0.444444	0.444444
<b>SCL</b>	0.485207	0.480769	0.485207	0.480769	0.480769	n/a	n/a	n/a
<b>Others</b>	0.482353	0.491111	0.482353	0.474684	0.474684	0.450704	0.438356	0.438356

When analyzing the short route, we have found airports that receive and transmit information, in our case, passengers who must necessarily make a transit to continue their journey (Betweenness). A short route can have one or more transit airports (Closeness). If there is a

connection (air route) between two airports with a third one, it is possible that the first two are also connected. This concept is analyzed in the following section.

#### 4.4.4 Clustering Coefficient

The chance that if two airports are linked to a third one, they are also linked directly to each other (Prabhakar and Anbarasi, 2021). That is to say, in simpler terms, the possibility of ensuring that three vertices or nodes are connected, or rather, that they form a triangle.

Table 4.7: Total Triangles According to Clustering Coefficient

Analysis	2019		2022		2026	
	Clustering	Triangles	Clustering	Triangles	Clustering	Triangles
A1	0.651	9	0.693	13	n/a	n/a
A2	0.651	9	0.693	13	0.764	22
A3	0.513	4	0.553	6	0.571	8

From Table 4.7, it can be observed that a high Clustering value represents a high possibility of completing triangles. However, it does not necessarily have a high Density value, as shown in Table 4.4, since the number of connections does not explicitly guarantee that airports are interconnected among all.

The level of node connectivity allows for determining the degree of each node and the average degree of the network, which is presented below.

#### 4.4.5 Average Degree

The average degree may indicate whether a network has improved its connectivity when we compare it between two different years (Güner and Keziban Seckin, 2023). Thus, in A3, the average degree increased slightly from 2.193 to 2.526 between 2019 and 2026; therefore, there are a improvement in network connectivity.

#### **4.4.6 Modularity**

According to (Ji et al., 2015), a high modularity represents dense connections at nodes of the same modules, but sparse connections between nodes of different modules. In simpler terms, the ability to detect communities within the network is a result of Modularity (Vahidzadeh et al., 2021; Guimerà et al., 2005).

The Modularity metric has revealed significant results. With a modularity equal to 0.000 and up to 12 identified communities (see Table 4.4, *A1* and *A3*), our network displays a disorganized structure, where airports are not closely connected to one another. This lack of clustering suggests that connections between airports are randomly spread across the network, without forming specific groups of highly interconnected airports.

A Modularity close to zero indicates that airports are connected in a way that does not form clear and distinct communities. In other words, there are no natural groupings of airports that have significantly more connections within their group compared to connections with airports outside their group. This absence of a clear community structure leads to randomly distributed connections between airports throughout the network, without forming specific groups of highly interconnected airports.

### **4.5 Findings**

#### **4.5.1 Analysis 1**

Considering that *A1* address the network with all the airports that have an operation permit from the CAA, even those where no commercial flights are performed. In other words, *A1* shows the network in its natural state, without modifying the structure of its components. Therefore, the results obtained in this section give the original typology of the network.

The first thing that stands out is the value of Diameter, making 3 transfers to move from

one airport to another could be acceptable in a network where geopolitical conditions is developing; however, a low Density value is evident which means that the network does not reach an acceptable connectivity category.

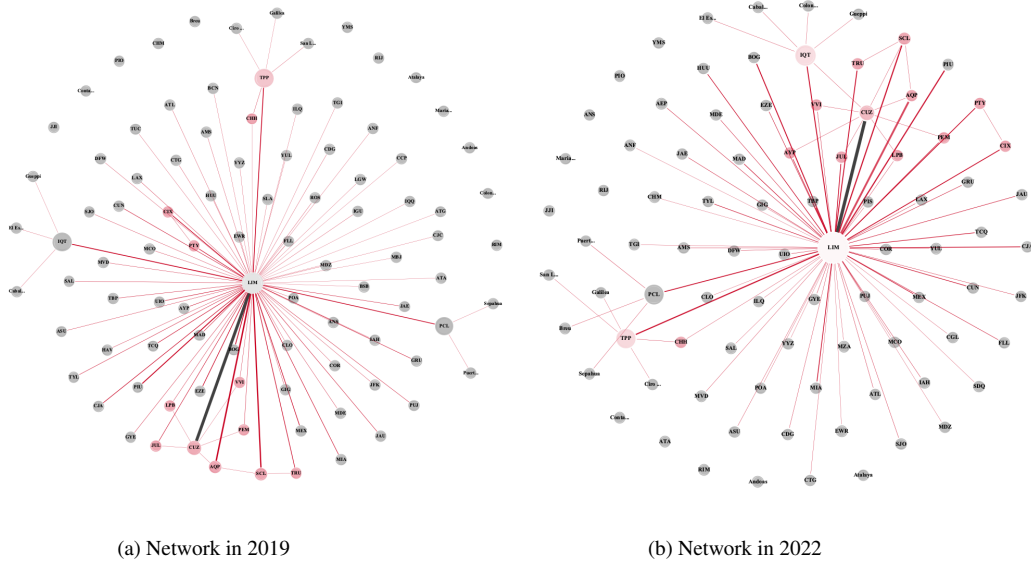


Figure 4.5: AI in Network 2019 and 2022

A high and differentiated Betweenness and Closeness values is observed in AI. It has already been mentioned that LIM and four other airports (CUZ, IQT, TPP and PCL) play an important role in the network. Their shortcomings or failures could produce considerable impact on the network. If we insert the airports to the network we will have "brought closer" the airports and therefore the degree of closeness will be increased.

The Clustering value in 2022 indicates how the airport is better configured and manages to ensure the connection of airports with each other reaching the highest number of triangles that can be obtained in this study. This implies that the network can improve its efficiency.

In other words, the values of Betweenness and Centrality are sacrificed for Density. In this sense, it can be pointed out that the purpose of optimizing a network from the approach of efficiency and capacity should be to find the balance between reaching acceptable values of

Network Density, i.e. increasing the degree of the network to reach capacity and guaranteeing centrality and Betweenness to make it efficient.

#### 4.5.2 Analysis 2

This analysis considers the operation of the second runway at LIM. It also takes into account the improvement and modernization of the CIX and PIU airports. And, above all, the entry into operation of the new Chinchero International Airport – CUZ – which has better characteristics than the current one, allowing direct entry and departure of higher performance aircraft from CUZ to SCL, BOG, PTY, MIA, EZE, AEP, MEX, GRU, LPB (see A.6).

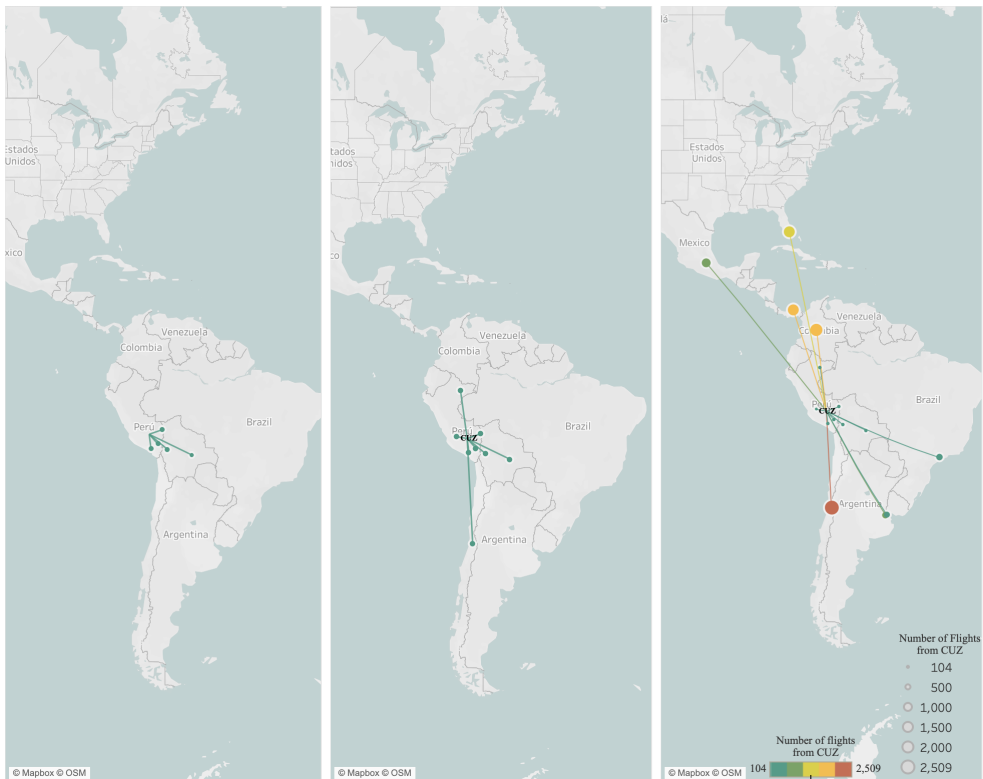


Figure 4.6: Evolution of the Flights from CUZ in 2019; 2022 and 2026

Then, under these parameters, we find a network with a Diameter value equal to 4, sim-

ilar to the Indian network (Bagler, 2008; Mallick et al., 2022) but below the values of the networks of China (Wang et al., 2011) and Australia (Hossain and Alam, 2017) which have diameters equal to 7 and 5, respectively (See Table 4.8).

This would mean at least 3 transfers to complete a trip between the airports that compose the Peruvian network. However, it does not represent a limitation for the network considering the tendency of the network itself to adopt LIM and CUZ as Hub airports and IQT, PCL, TPP as Spoke airports (Burgos, 1991; Suau-Sanchez et al., 2016).

Indeed, in 2026, an improvement in network connectivity at the international level is observed with the entry into operation of Chinchero that manages to connect with strategic Hubs for the region (Burgos, 1991; Lee, 2009), this is reflected in the increase of the Density value (0.038 in 2019; 0.040 in 2022 and 0.042 in 2026) but still not enough to improve the category of the network, defining it as a network with very low connection, reduced cohesion and membership Hansen et al. (2019).

Table 4.8: Comparative of Airport Metrics

Region	Network	Author	Airports	Connections	Diameter	Degree		Path Length Average	Clustering Coefficient
						Max.	Avg.		
Global	Global	Guimerà & Amaral (2004)	3883	27051	n.a.	n.a.	13.93	4.4	0.620
	Global	Prabhakar & Anbarasi (2021)	7544	33804	12	433	10.42	3.95	0.450
Europe	Italy	Guida & Maria (2007)	50	310	n.a.	n.a.	12.4	1.98 - 2.14	0.660
	Spain	Trobajo & Carriegos (2022)	40	-	-	-	11.8	1.76	0.730
	Turkey* - 2018	Guner & Keziban Seckin (2023)	47	428	3	n.a.	10.34	1.757	0.739
	Turkey* - 2023	Guner & Keziban Seckin (2023)	51	580	3	n.a.	13.8	1.708	0.620
Asia	China	Wang et al. (2011)	144	1018	5	n.a.	14.14	2.23	0.690
	India	Bagler (2008)	79	455	4	n.a.	11.52	2.26	0.660
	India	Mallick (2022)	109	10701	4	n.a.		2.25	0.614
Oceania	Australia	Hossain & Alam (2017)	131	596	7	n.a.	9.1	2.9	0.500
America	USA	Xu & Harriss (2008)	272	6566	n.a.	n.a.	48.28	1.84 - 1.93	0.73 - 0.78
	Brasil	Rocha (2009)	142		5		10.28	2.34	0.630
	Argentina - National Network	Guillaumet (2018)	39	168	n.a.	37	4.308	1.86	0.417
	Argentina Network)	Guillaumet (2018)	89	3347	n.a.	54	3.7428	2.4484	0.273
	Peru Network 2022	This Thesis	76	87	4	65	2.289	2.214	0.693
	Peru Network 2026	This Thesis	76	94	4	65	2.474	2.212	0.756



A network with these characteristics in the Density metric has an impact on the Average Path Length value, since a reduced number of connections increases this value.

In Figure 4.7 we can observe the positive evolution of the network in terms of Betweenness (represented in the image by the size of the nodes) and Closeness (represented in the image by the color of the nodes). These values have been presented in Tables 4.5 and 4.6.

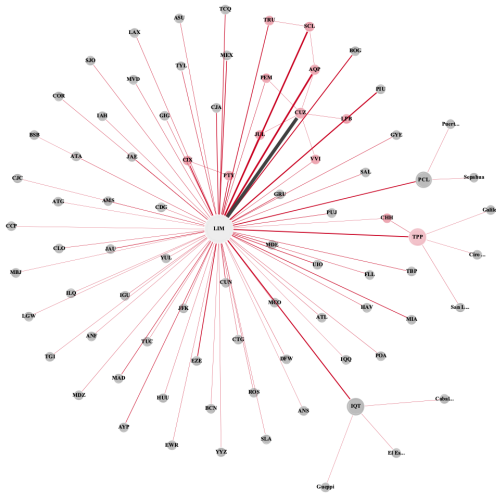
From 2019 to 2022 the average network grade has increased from 2.193 to 2.289 and by 2026 an equal value 2.526 is expected. A modularity of 0.00000 means that the airports in the network are not forming clusters more densely interconnected with each other than with other airports outside their cluster, in other words they do not form clear and distinct communities, the connections between airports are randomly distributed throughout the network (see Table 4.4).

In this scenario we note that LIM represents an Intermediate Airport for the Global network but in the national network it represents the only Central Airport. In 2026, CUZ joins the Global network as the second Intermediate Airport and in the national network it contributes positively to the metrics. This means that the construction and operation of the new Chinchero International Airport in Cuzco will have a positive impact on the network based on the values obtained and the graphs presented.

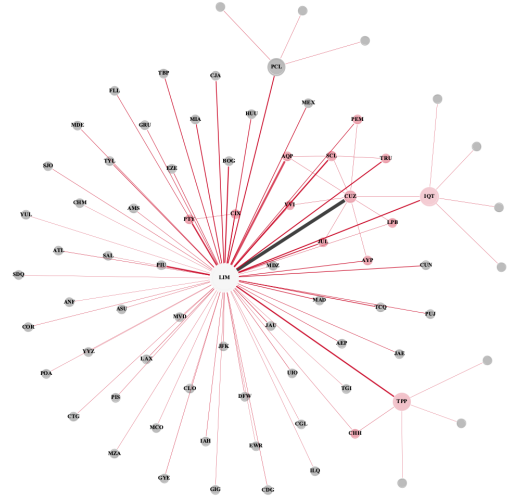
We will now relate these results to our section's hypothesis. It was mentioned earlier that the capacity of a system is directly related to the capacity of each component (node or link), the failure generated by each airport will trigger a cascade in the network (Motter and Lai, 2002; Cumelles et al., 2021). In this sense, we will focus the analysis only on the airports that have the highest degree of Betweenness (LIM, IQT, PCL, TPP and CUZ) we do not consider SCL because it is not in national territory.

We can observe that the degree of centrality increases from 2019 to 2026 due to the new routes connecting Chinchero Airport, in spite of that the value of the short path in 2026 is

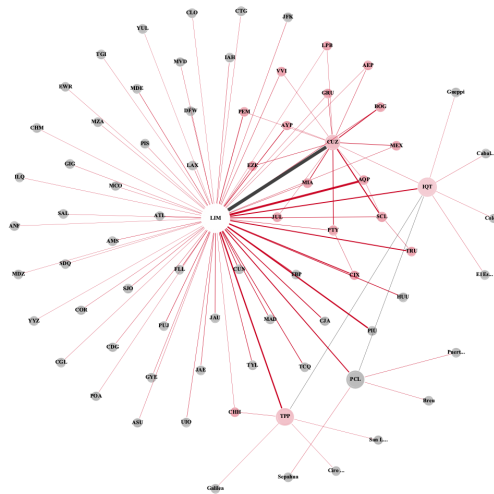
reduced. This means that this reduction would also be reflected in the network capacity as these parameters are related. Therefore, we cannot ensure an improvement in the capacity of a network only with the increase in the value of the degree of centrality.



(a) Network in 2019



(b) Network in 2022



(c) Network in 2026

Figure 4.7: A2 in Network 2019; 2022 and 2026

In Table 4.9 we observe the variations in the degrees of Betweenness in the different

years. We observe in 2022 a reduction in the Betweenness value of LIM and a considerable increase in the other airports of the system. By 2026 the Betweenness value of LIM continues to decrease and the growth of the other airports is maintained but with a lower proportion. This means that one node of the network loses capacity but the others gain capacity and this is good for the system since in general the system will be increasing its capacity.

Table 4.9: Variations in the Betweenness Centrality in A2

<b>Airport</b>	2019	2022	$\Delta$	2026	$\Delta$
LIM	0.990063	0.974955	-1.51%	0.933694	-4.13%
IQT	0.072267	0.104505	3.22%	0.108829	0.43%
TPP	0.072267	0.078919	0.66%	0.079820	0.09%
PCL	0.048479	0.078919	3.04%	0.078919	0.00%
CUZ	0.001506	0.00991	0.84%	0.028829	1.89%
AQP	0.000151	0.000000	-0.01%	0.000000	0.00%
SCL	0.000151	0.00036	0.02%	0.00036	0.00%
PTY	0.000000	0.000000	0.00%	0.00018	0.01%
others	0.000000	0.000000	0.00%	0.000000	0.00%

Considering the unique aspects of this system, the variation in the capacity values of a system could be generated either by inserting a new airport into the system or by enabling new air routes in the system.

Regarding the efficiency of the system, we have pointed out that its best result is obtained when there are fewer short paths from one point to another, or rather, if we increase their degree of proximity. This is reflected in Table 4.10, we can observe the increase presented by CUZ airport and how in 2026 it positively impacts the system allowing it to be more efficient and ensuring a growth in the centrality values of the entire system.

Table 4.10: Variations in the Closeness Centrality in A2

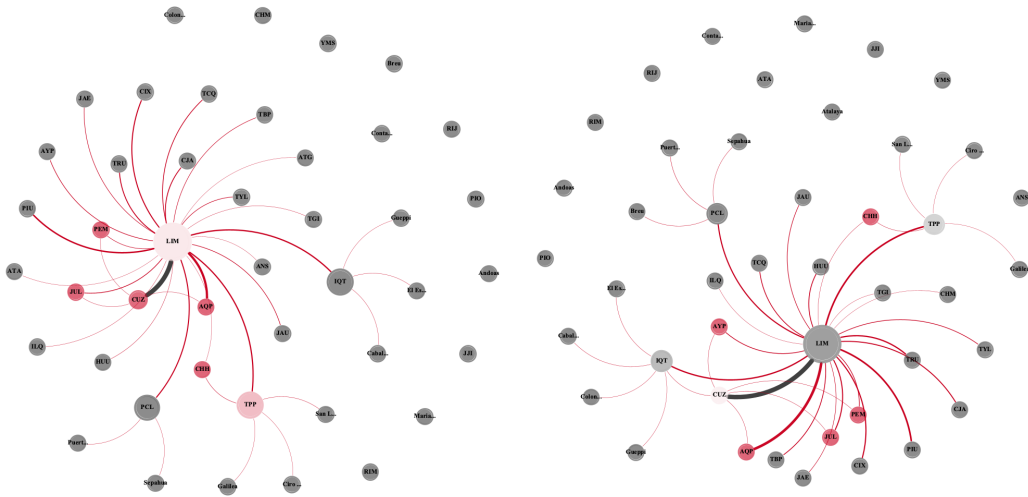
<b>Airport</b>	2019	2022	$\Delta$	2026	$\Delta$
LIM	0.911111	0.882353	-2.8758%	0.882353	0.00%
IQT	0.49697	0.500000	+0.60%	0.528169	5.60%
TPP	0.50000	0.493421	-1.40%	0.510204	3.30%
PCL	0.491018	0.490196	-0.20%	0.506757	3.47%
CUZ	0.493976	0.510204	3.25%	0.535714	5.49%
AQP	0.485207	0.477707	-1.44%	0.477707	0.00%
SCL	0.485207	0.480769	-0.83%	0.480769	0.00%
others	0.482353	0.474684	-1.45%	0.474684	0.00%

On the other hand, if we reduce the value of short routes we will be increasing the value of centrality and Density, so we will have a network with higher Density and this will result in a better connected and efficient network. Therefore we can affirm that making improvements in the Betweenness degree allows to increase the efficiency of the system.

### 4.5.3 Analysis 3

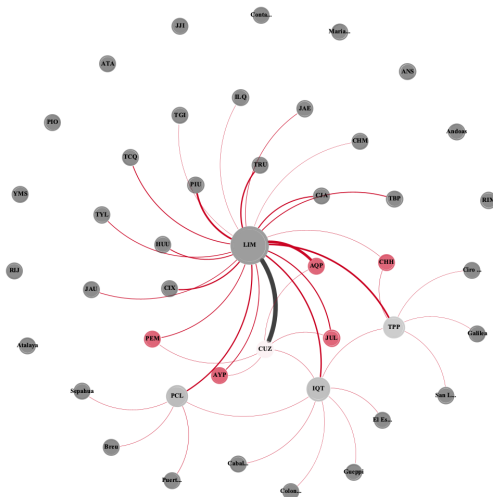
As in A2, we have taken into account the modernization of CIX and PIU and the entry into operation of new infrastructure at LIM and CUZ (see A.15).

We focus our attention on connectivity, which is one of the main roles of airports, analyzing territories where geographical conditions are adverse to implement other modes of transportation. Cities with reduced possibilities of connecting to others with greater commercial dynamics represent the source of study of researches such as those of (Debbage Keith, 1999; Green, 2007; Tvetter, 2017).



(a) Network in 2019

(b) Network in 2022



(c) Network in 2026

Figure 4.8:  $A_3$  in Network 2019; 2022 and 2026

According to the metrics obtained in the  $A_3$  we can observe that, developing and implementing intermediate airports to later connect them with the peripheral airports of the network can be positive for the system.

In the structure of the national air network, which is the particular objective of this analy-

sis, inconveniences to travel through it are observed, especially due to the existence of public airfields authorized for operation and that are not connected to the network.

In spite of this, a value equal to 4 in the Diameter metric, defined as the longest of all short routes (Hossain and Alam, 2017; Bagler, 2008) and which would mean a somewhat significant number of transfers to complete the journey (3 flights) (Bagler, 2008; Güner and Keziban Seckin, 2023), does not represent a limitation for the network, considering that these connections occur between two peripheral airports. Indeed a low value should be preferred for an ideal airport network (Lordan et al., 2014; Güner and Keziban Seckin, 2023) however it would depend on the characteristics of the network, as is the case of Peru's network that becomes necessary to connect peripheral airports whose only efficient means of transport is air transport.

Regarding the Network Density, although the values from 2019 to 2026 will experience an increase in its performance, they keep the network in the lowest category in the range of values of other networks, defining it as a network with very low connection, reduced cohesion and membership. This limitation directly affects the value of Average Path Length since the lower the number of connections between nodes, the higher this value will be.

On the other hand, we can observe the presence of airports that clearly play the role of intermediate airports (LIM, IQT, TPP, PCL and CUZ), the size of the nodes in Figure 4.8 denote the degree of Betweenness of the airports in the network and are related to the values presented in the table 4.5.

We found an important detail object of this research, the airports IQT, TPP, PCL and CUZ present a slight increase in their Betweenness values but it has not been enough to improve the low network connection (Diameter and Density). This increase has generated a reduction in the Betweenness values of LIM, which could mean a release of flights and an increase in its capacity.

In this study, the analysis of closeness is more complex LIM, CHH and AQP reduce their values while IQT, TPP, PCL and CUZ increase. This increase is due to the new routes that connect these nodes to each other, reducing the relative value of the others. This variation, in turn, favorably modifies the Clustering and triangle formation values that represent the efficiency in air connectivity.

According to Table 4.4, from 2019 to 2022 the average degree of the network has increased from 1.636 to 1.727 and by 2026 an equal value 1.818 is expected. These values are directly related to Clustering which in turn depend on Closeness.

A modularity of 0.00000 (see Table 4.4) indicates that the airports in the network are not forming clusters more densely interconnected with each other than with other airports outside their cluster, i.e. they do not form clear and distinct communities, the connections between airports are randomly distributed throughout the network.

#### **4.6 Limitations and future researches**

The findings of this study provide a valuable theoretical contribution to propose strategies to optimize the capacity and efficiency of a given airport system and offer valuable perspectives for future research in the field of air transportation regarding the construction of new airports and route planning.

As part of the limitations of the present study, equal treatment of all nodes is considered, however, this is not exactly the case for airports. For example, a given airport can only receive smaller aircraft than another airport and therefore the links could even have different characteristics, such as the frequency of flights and number of passengers carried. This would generate significant changes in closeness. This would generate a research topic with an analysis at this level of detail.

The analysis does not propose passenger segmentation, so understanding their reasons

for moving from one airport to another may allow a better understanding of the behavior and structure of the network. For example, for subsidized flights, passengers' only intention is to reach the major city to do their business, but if the approach is more tourism-oriented, other more precise solutions can be proposed.

On the other hand, it is possible to go further in this analysis by knowing the behavior of passengers and their final destinations. In this way, it would be possible to know exactly the Diameter or the number of transfers needed to get from a certain point to another destination in the world. This represents a greater degree of work on the data collected through passenger surveys.



## CHAPTER 5

### CONCLUSIONS

One third of the authorized public aerodromes in Peru do not have commercial flights. Thus, the network is poorly connected, with a reduced cohesion and membership.

Some authors have pointed out that in a network it is preferable to have more direct flights between airports, which means a low Diameter value. However, in the case of Peru, we observe that intermediate airports play an important role in the development of isolated cities, which would lead to an increase in the Diameter value of the network.

When modularity is low (or in this case, zero), it may be useful to consider adjustments to routes or connections between airports to improve the efficiency of the system, given that there are no natural groupings of airports that need to be specially addressed. It is important to note that, although modularity is low, it is still possible to obtain a functional and efficient airport network based on other criteria, such as accessibility, geographic coverage and capacity to handle passenger traffic.

In other words, the airport, according to its geographical conditions, must first bring passengers closer to cities with intermediate airports and then connect them with other means of transportation, which could lead to the operation of peripheral airports.

On the other hand, we cannot assure an improvement in the capacity of a network only by increasing the value of the degree of centrality, but we can when there is an improvement in the degree of Betweenness. Furthermore, we observe that either the increase in the degree of centrality or improvements in the degree of Betweenness, or both together, guarantee an improvement in the efficiency of the network.

With this we can say that the construction of the Chinchero International Airport brings significant benefits to the system, notably increasing the efficiency and capacity of the Peru-

vian network.

Then, it can be suggested that the construction or investment in a certain airport should be analyzed from the approach of covering the lack of connectivity in a certain sector of the network, where it should not necessarily be connected to the central airports but to other airports outside the current system or to the intermediate airports and vice versa.

This consideration will significantly improve the typology of the network. That is, it will increase the network capacity by improving the network grade indicator and the network efficiency by improving the centrality and Betweenness indicators.

This study can help to generate a methodological framework that can be replicated by other countries to generate strategies that allow them to improve the Capacity and Efficiency of their air transport system. Considering that it appears that a bridge between strategic planning and academic research on airport networks is needed to achieve the objectives that CAMP seeks.

Future network studies could consider the capacity factor of the entire system, i.e. how many aircraft in airspace and on the ground the network supports and how many are currently operating in the system.

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# Appendix A

## List of Nodes and Links for year and analysis

Table A.1: Network in 2019, Nodes for A1

Id	Label	Id	Label	Id	Label
1	AMS	33	El Estrecho	65	MIA
2	Andoas	34	EWR	66	MVD
3	ANF	35	EZE	67	PCL
4	ANS	36	FLL	68	PEM
5	AQP	37	Galilea	69	PIO
6	ASU	38	GIG	70	PIU
7	ATA	39	GRU	71	POA
8	Atalaya	40	Gueppi	72	PTY
9	ATG	41	GYE	73	Puerto Esperanza
10	ATL	42	HAV	74	PUJ
11	AYP	43	HUU	75	RIJ
12	BCN	44	IAH	76	RIM
13	BOG	45	IGU	77	ROS
14	Breu	46	ILQ	78	SAL
15	BSB	47	IQQ	79	San Lorenzo
16	Caballococha	48	IQT	80	SCL
17	CCP	49	JAE	81	Sepahua
18	CDG	50	JAU	82	SJO
19	CHH	51	JFK	83	SLA
20	CHM	52	JJI	84	TBP
21	Ciro Alegria	53	JUL	85	TCQ
22	CIX	54	LAX	86	TGI
23	CJA	55	LGW	87	TPP
24	CJC	56	LIM	88	TRU
25	CLO	57	LPB	89	TUC
26	Contamana	58	MAD	90	TYL
27	Colonia de Angamos	59	Maria Reiche Neuman	91	UIO
28	COR	60	MBJ	92	VVI
29	CTG	61	MCO	93	YMS
30	CUN	62	MDE	94	YUL
31	CUZ	63	MDZ	95	YYZ
32	DFW	64	MEX		

Table A.2: Network in 2019, Links for A1

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	1	365	Comercial	undirected	56	59	0	No Comercial	undirected
56	2	0	No Comercial	undirected	56	60	29	Comercial	undirected
56	3	143	Comercial	undirected	56	61	557	Comercial	undirected
56	4	50	Comercial	undirected	56	62	661	Comercial	undirected
56	5	7030	Comercial	undirected	56	63	296	Comercial	undirected
56	6	663	Comercial	undirected	56	64	2560	Comercial	undirected
56	7	39	Comercial	undirected	56	65	1858	Comercial	undirected
56	8	0	No Comercial	undirected	56	66	647	Comercial	undirected
56	9	19	Comercial	undirected	56	67	3043	Comercial	undirected
56	10	365	Comercial	undirected	56	68	886	Comercial	undirected
56	11	1350	Comercial	undirected	56	69	0	No Comercial	undirected

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Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	12	172	Comercial	undirected	56	70	4272	Comercial	undirected
56	13	3410	Comercial	undirected	56	71	366	Comercial	undirected
56	14	0	No Comercial	undirected	56	72	2228	Comercial	undirected
56	15	21	Comercial	undirected	56	73	0	No Comercial	undirected
56	16	0	No Comercial	undirected	56	74	997	Comercial	undirected
56	17	4	Comercial	undirected	56	75	0	No Comercial	undirected
56	18	291	Comercial	undirected	56	76	0	No Comercial	undirected
56	19	53	Comercial	undirected	56	77	364	Comercial	undirected
56	20	0	No Comercial	undirected	56	78	720	Comercial	undirected
56	21	0	No Comercial	undirected	56	79	0	No Comercial	undirected
56	22	2946	Comercial	undirected	56	80	6080	Comercial	undirected
56	23	2268	Comercial	undirected	56	81	0	No Comercial	undirected
56	24	79	Comercial	undirected	56	82	574	Comercial	undirected
56	25	400	Comercial	undirected	56	83	187	Comercial	undirected
56	26	0	No Comercial	undirected	56	84	938	Comercial	undirected
56	27	0	No Comercial	undirected	56	85	1869	Comercial	undirected
56	28	421	Comercial	undirected	56	86	145	Comercial	undirected
56	29	414	Comercial	undirected	56	87	3590	Comercial	undirected
56	30	1503	Comercial	undirected	56	88	2502	Comercial	undirected
56	31	15060	Comercial	undirected	56	89	233	Comercial	undirected
56	32	371	Comercial	undirected	56	90	1135	Comercial	undirected
56	33	0	No Comercial	undirected	56	91	1625	Comercial	undirected
56	34	295	Comercial	undirected	56	92	603	Comercial	undirected
56	35	2635	Comercial	undirected	56	93	0	No Comercial	undirected
56	36	656	Comercial	undirected	56	94	156	Comercial	undirected
56	37	0	No Comercial	undirected	56	95	209	Comercial	undirected
56	38	574	Comercial	undirected	48	33	122	Subdiary	undirected
56	39	1423	Comercial	undirected	48	16	124	Subdiary	undirected
56	40	0	No Comercial	undirected	48	27	0	Subdiary	undirected
56	41	814	Comercial	undirected	48	40	33	Subdiary	undirected
56	42	628	Comercial	undirected	67	14	0	Subdiary	undirected
56	43	300	Comercial	undirected	67	81	76	Subdiary	undirected
56	44	396	Comercial	undirected	67	73	119	Subdiary	undirected
56	45	300	Comercial	undirected	87	19	513	Subdiary	undirected
56	46	124	Comercial	undirected	87	21	29	Subdiary	undirected
56	47	38	Comercial	undirected	87	79	231	Subdiary	undirected
56	48	3732	Comercial	undirected	87	37	40	Subdiary	undirected
56	49	1055	Comercial	undirected	5	80	156	Comercial	undirected
56	50	1281	Comercial	undirected	88	80	156	Comercial	undirected
56	51	454	Comercial	undirected	31	57	156	Comercial	undirected
56	52	0	No Comercial	undirected	31	92	104	Comercial	undirected
56	53	1626	Comercial	undirected	22	72	324	Comercial	undirected
56	54	678	Comercial	undirected	31	5	156	Comercial	undirected
56	55	90	Comercial	undirected	31	68	156	Comercial	undirected
56	57	730	Comercial	undirected	31	53	156	Comercial	undirected
56	58	1330	Comercial	undirected					

Table A.3: Network in 2019, Nodes for A2

Id	Label	Id	Label	Id	Label
1	AMS	35	EZE	65	MIA
3	ANF	36	FLL	66	MVD
4	ANS	37	Galilea	67	PCL

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Id	Label	Id	Label	Id	Label
5	AQP	38	GIG	68	PEM
6	ASU	39	GRU	70	PIU
7	ATA	40	Gueppi	71	POA
9	ATG	41	GYE	72	PTY
10	ATL	42	HAV	73	Puerto Esperanza
11	AYP	43	HUU	74	PUJ
12	BCN	44	IAH	77	ROS
13	BOG	45	IGU	78	SAL
15	BSB	46	ILQ	79	San Lorenzo
16	Caballococha	47	IQQ	80	SCL
17	CCP	48	IQT	81	Sepahua
18	CDG	49	JAE	82	SJO
19	CHH	50	JAU	83	SLA
21	Ciro Alegria	51	JFK	84	TBP
22	CIX	53	JUL	85	TCQ
23	CJA	54	LAX	86	TGI
24	CJC	55	LGW	87	TPP
25	CLO	56	LIM	88	TRU
28	COR	57	LPB	89	TUC
29	CTG	58	MAD	90	TYL
30	CUN	60	MBJ	91	UIO
31	CUZ	61	MCO	92	VVI
32	DFW	62	MDE	94	YUL
33	El Estrecho	63	MDZ	95	YYZ
34	EWR	64	MEX		

Table A.4: Network in 2019, Links for A2

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	1	365	Comercial	undirected	56	61	557	Comercial	undirected
56	3	143	Comercial	undirected	56	62	661	Comercial	undirected
56	4	50	Comercial	undirected	56	63	296	Comercial	undirected
56	5	7030	Comercial	undirected	56	64	2560	Comercial	undirected
56	6	663	Comercial	undirected	56	65	1858	Comercial	undirected
56	7	39	Comercial	undirected	56	66	647	Comercial	undirected
56	9	19	Comercial	undirected	56	67	3043	Comercial	undirected
56	10	365	Comercial	undirected	56	68	886	Comercial	undirected
56	11	1350	Comercial	undirected	56	70	4272	Comercial	undirected
56	12	172	Comercial	undirected	56	71	366	Comercial	undirected
56	13	3410	Comercial	undirected	56	72	2228	Comercial	undirected
56	15	21	Comercial	undirected	56	74	997	Comercial	undirected
56	17	4	Comercial	undirected	56	77	364	Comercial	undirected
56	18	291	Comercial	undirected	56	78	720	Comercial	undirected
56	19	53	Comercial	undirected	56	80	6080	Comercial	undirected
56	22	2946	Comercial	undirected	56	82	574	Comercial	undirected
56	23	2268	Comercial	undirected	56	83	187	Comercial	undirected
56	24	79	Comercial	undirected	56	84	938	Comercial	undirected
56	25	400	Comercial	undirected	56	85	1869	Comercial	undirected
56	28	421	Comercial	undirected	56	86	145	Comercial	undirected
56	29	414	Comercial	undirected	56	87	3590	Comercial	undirected
56	30	1503	Comercial	undirected	56	88	2502	Comercial	undirected
56	31	15060	Comercial	undirected	56	89	233	Comercial	undirected
56	32	371	Comercial	undirected	56	90	1135	Comercial	undirected

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Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	34	295	Comercial	undirected	56	91	1625	Comercial	undirected
56	35	2635	Comercial	undirected	56	92	603	Comercial	undirected
56	36	656	Comercial	undirected	56	94	156	Comercial	undirected
56	38	574	Comercial	undirected	56	95	209	Comercial	undirected
56	39	1423	Comercial	undirected	48	33	122	Subidiary	undirected
56	41	814	Comercial	undirected	48	16	124	Subidiary	undirected
56	42	628	Comercial	undirected	48	40	33	Subidiary	undirected
56	43	300	Comercial	undirected	67	81	76	Subidiary	undirected
56	44	396	Comercial	undirected	67	73	119	Subidiary	undirected
56	45	300	Comercial	undirected	87	19	513	Subidiary	undirected
56	46	124	Comercial	undirected	87	21	29	Subidiary	undirected
56	47	38	Comercial	undirected	87	79	231	Subidiary	undirected
56	48	3732	Comercial	undirected	87	37	40	Subidiary	undirected
56	49	1055	Comercial	undirected	5	80	156	Comercial	undirected
56	50	1281	Comercial	undirected	88	80	156	Comercial	undirected
56	51	454	Comercial	undirected	31	57	156	Comercial	undirected
56	53	1626	Comercial	undirected	31	92	104	Comercial	undirected
56	54	678	Comercial	undirected	22	72	324	Comercial	undirected
56	55	90	Comercial	undirected	31	5	156	Comercial	Undirected
56	57	730	Comercial	undirected	31	68	156	Comercial	undirected
56	58	1330	Comercial	undirected	31	53	156	Comercial	undirected
56	60	29	Comercial	undirected					

Table A.5: Network in 2019, Nodes for A3

Id	Label	Id	Label	Id	Label
2	Andoas	31	CUZ	69	PIO
4	ANS	33	El Estrecho	70	PIU
5	AQP	37	Galilea	73	Puerto Esperanza
7	ATA	40	Gueppi	75	RIJ
9	ATG	43	HUU	76	RIM
11	AYP	46	ILQ	79	San Lorenzo
14	Breu	48	IQT	81	Sepahua
16	Cabalcocha	49	JAE	84	TBP
19	CHH	50	JAU	85	TCQ
20	CHM	52	JJI	86	TGI
21	Ciro Alegria	53	JUL	87	TPP
22	CIX	56	LIM	88	TRU
23	CJA	59	Maria Reiche Neuman	90	TYL
26	Contamana	67	PCL	93	YMS
27	Colonia de Angamos	68	PEM		

Table A.6: Network in 2019, Links for A3

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	2	0	No Comercial	undirected	56	68	886	Comercial	undirected
56	4	50	Comercial	undirected	56	69	0	No Comercial	undirected
56	5	7030	Comercial	undirected	56	70	4272	Comercial	undirected
56	7	39	Comercial	undirected	56	73	0	No Comercial	undirected
56	9	19	Comercial	undirected	56	75	0	No Comercial	undirected

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Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	11	1350	Comercial	undirected	56	76	0	No Comercial	undirected
56	14	0	No Comercial	undirected	56	79	0	No Comercial	undirected
56	16	0	No Comercial	undirected	56	81	0	No Comercial	undirected
56	19	53	Comercial	undirected	56	84	938	Comercial	undirected
56	20	0	No Comercial	undirected	56	85	1869	Comercial	undirected
56	21	0	No Comercial	undirected	56	86	145	Comercial	undirected
56	22	2946	Comercial	undirected	56	87	3590	Comercial	undirected
56	23	2268	Comercial	undirected	56	88	2502	Comercial	undirected
56	26	0	No Comercial	undirected	56	90	1135	Comercial	undirected
56	27	0	No Comercial	undirected	56	93	0	No Comercial	undirected
56	31	15060	Comercial	undirected	48	33	122	Subidiary	undirected
56	33	0	No Comercial	undirected	48	16	124	Subidiary	undirected
56	37	0	No Comercial	undirected	48	27	0	Subidiary	undirected
56	40	0	No Comercial	undirected	48	40	33	Subidiary	undirected
56	43	300	Comercial	undirected	67	14	0	Subidiary	undirected
56	46	124	Comercial	undirected	67	81	76	Subidiary	undirected
56	48	3732	Comercial	undirected	67	73	119	Subidiary	undirected
56	49	1055	Comercial	undirected	87	19	513	Subidiary	undirected
56	50	1281	Comercial	undirected	87	21	29	Subidiary	undirected
56	52	0	No Comercial	undirected	87	79	231	Subidiary	undirected
56	53	1626	Comercial	undirected	87	37	40	Subidiary	undirected
56	56	0	No Comercial	undirected	31	5	156	Comercial	Undirected
56	59	0	No Comercial	undirected	31	68	156	Comercial	undirected
56	67	3043	Comercial	undirected	31	53	156	Comercial	undirected

Table A.7: Network in 2022, Nodes for A1

Id	Label	Id	Label	Id	Label
1	AMS	33	El Estrecho	65	MIA
2	Andoas	34	EWR	66	MVD
3	ANF	35	EZE	67	PCL
4	ANS	36	FLL	68	PEM
5	AQP	37	Galilea	69	PIO
6	ASU	38	GIG	70	PIU
7	ATA	39	GRU	71	POA
8	Atalaya	40	Gueppi	72	PTY
9	ATG	41	GYE	73	Puerto Esperanza
10	ATL	42	HAV	74	PUJ
11	AYP	43	HUU	75	RIJ
12	BCN	44	IAH	76	RIM
13	BOG	45	IGU	77	ROS
14	Breu	46	ILQ	78	SAL
15	BSB	47	IQQ	79	San Lorenzo
16	Cabalcocha	48	IQT	80	SCL
17	CCP	49	JAE	81	Sepahua
18	CDG	50	JAU	82	SJO
19	CHH	51	JFK	83	SLA
20	CHM	52	JJI	84	TBP
21	Ciro Alegria	53	JUL	85	TCQ
22	CIX	54	LAX	86	TGI
23	CJA	55	LGW	87	TPP
24	CJC	56	LIM	88	TRU
25	CLO	57	LPB	89	TUC

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Id	Label	Id	Label	Id	Label
26	Contamana	58	MAD	90	TYL
27	Colonia de Angamos	59	Maria Reiche Neuman	91	UIO
28	COR	60	MBJ	92	VVI
29	CTG	61	MCO	93	YMS
30	CUN	62	MDE	94	YUL
31	CUZ	63	MDZ	95	YYZ
32	DFW	64	MEX		

Table A.8: Network in 2022, Links for A1

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	1	365	Comercial	undirected	56	59	0	No Comercial	undirected
56	2	0	No Comercial	undirected	56	60	29	Comercial	undirected
56	3	143	Comercial	undirected	56	61	557	Comercial	undirected
56	4	50	Comercial	undirected	56	62	661	Comercial	undirected
56	5	7030	Comercial	undirected	56	63	296	Comercial	undirected
56	6	663	Comercial	undirected	56	64	2560	Comercial	undirected
56	7	39	Comercial	undirected	56	65	1858	Comercial	undirected
56	8	0	No Comercial	undirected	56	66	647	Comercial	undirected
56	9	19	Comercial	undirected	56	67	3043	Comercial	undirected
56	10	365	Comercial	undirected	56	68	886	Comercial	undirected
56	11	1350	Comercial	undirected	56	69	0	No Comercial	undirected
56	12	172	Comercial	undirected	56	70	4272	Comercial	undirected
56	13	3410	Comercial	undirected	56	71	366	Comercial	undirected
56	14	0	No Comercial	undirected	56	72	2228	Comercial	undirected
56	15	21	Comercial	undirected	56	73	0	No Comercial	undirected
56	16	0	No Comercial	undirected	56	74	997	Comercial	undirected
56	17	4	Comercial	undirected	56	75	0	No Comercial	undirected
56	18	291	Comercial	undirected	56	76	0	No Comercial	undirected
56	19	53	Comercial	undirected	56	77	364	Comercial	undirected
56	20	0	No Comercial	undirected	56	78	720	Comercial	undirected
56	21	0	No Comercial	undirected	56	79	0	No Comercial	undirected
56	22	2946	Comercial	undirected	56	80	6080	Comercial	undirected
56	23	2268	Comercial	undirected	56	81	0	No Comercial	undirected
56	24	79	Comercial	undirected	56	82	574	Comercial	undirected
56	25	400	Comercial	undirected	56	83	187	Comercial	undirected
56	26	0	No Comercial	undirected	56	84	938	Comercial	undirected
56	27	0	No Comercial	undirected	56	85	1869	Comercial	undirected
56	28	421	Comercial	undirected	56	86	145	Comercial	undirected
56	29	414	Comercial	undirected	56	87	3590	Comercial	undirected
56	30	1503	Comercial	undirected	56	88	2502	Comercial	undirected
56	31	15060	Comercial	undirected	56	89	233	Comercial	undirected
56	32	371	Comercial	undirected	56	90	1135	Comercial	undirected
56	33	0	No Comercial	undirected	56	91	1625	Comercial	undirected
56	34	295	Comercial	undirected	56	92	603	Comercial	undirected
56	35	2635	Comercial	undirected	56	93	0	No Comercial	undirected
56	36	656	Comercial	undirected	56	94	156	Comercial	undirected
56	37	0	No Comercial	undirected	56	95	209	Comercial	undirected
56	38	574	Comercial	undirected	48	33	122	Subidiary	undirected
56	39	1423	Comercial	undirected	48	16	124	Subidiary	undirected
56	40	0	No Comercial	undirected	48	27	0	Subidiary	undirected
56	41	814	Comercial	undirected	48	40	33	Subidiary	undirected
56	42	628	Comercial	undirected	67	14	0	Subidiary	undirected

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Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	43	300	Comercial	undirected	67	81	76	Subdiary	undirected
56	44	396	Comercial	undirected	67	73	119	Subdiary	undirected
56	45	300	Comercial	undirected	87	19	513	Subdiary	undirected
56	46	124	Comercial	undirected	87	21	29	Subdiary	undirected
56	47	38	Comercial	undirected	87	79	231	Subdiary	undirected
56	48	3732	Comercial	undirected	87	37	40	Subdiary	undirected
56	49	1055	Comercial	undirected	5	80	156	Comercial	undirected
56	50	1281	Comercial	undirected	88	80	156	Comercial	undirected
56	51	454	Comercial	undirected	31	57	156	Comercial	undirected
56	52	0	No Comercial	undirected	31	92	104	Comercial	undirected
56	53	1626	Comercial	undirected	22	72	324	Comercial	undirected
56	54	678	Comercial	undirected	31	5	156	Comercial	undirected
56	55	90	Comercial	undirected	31	68	156	Comercial	undirected
56	57	730	Comercial	undirected	31	53	156	Comercial	undirected
56	58	1330	Comercial	undirected					

Table A.9: Network in 2022, Nodes for A2

Id	Label	Id	Label	Id	Label
1	AMS	35	EZE	65	MIA
3	ANF	36	FLL	66	MVD
4	ANS	37	Galilea	67	PCL
5	AQP	38	GIG	68	PEM
6	ASU	39	GRU	70	PIU
7	ATA	40	Gueppi	71	POA
9	ATG	41	GYE	72	PTY
10	ATL	42	HAV	73	Puerto Esperanza
11	AYP	43	HUU	74	PUJ
12	BCN	44	IAH	77	ROS
13	BOG	45	IGU	78	SAL
15	BSB	46	ILQ	79	San Lorenzo
16	Caballococha	47	IQQ	80	SCL
17	CCP	48	IQT	81	Sepahua
18	CDG	49	JAE	82	SJO
19	CHH	50	JAU	83	SLA
21	Ciro Alegria	51	JFK	84	TBP
22	CIX	53	JUL	85	TCQ
23	CJA	54	LAX	86	TGI
24	CJC	55	LGW	87	TPP
25	CLO	56	LIM	88	TRU
28	COR	57	LPB	89	TUC
29	CTG	58	MAD	90	TYL
30	CUN	60	MBJ	91	UIO
31	CUZ	61	MCO	92	VVI
32	DFW	62	MDE	94	YUL
33	El Estrecho	63	MDZ	95	YYZ
34	EWR	64	MEX		

Table A.10: Network in 2022, Links for A2

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	1	365	Comercial	undirected	56	61	557	Comercial	undirected
56	3	143	Comercial	undirected	56	62	661	Comercial	undirected
56	4	50	Comercial	undirected	56	63	296	Comercial	undirected
56	5	7030	Comercial	undirected	56	64	2560	Comercial	undirected
56	6	663	Comercial	undirected	56	65	1858	Comercial	undirected
56	7	39	Comercial	undirected	56	66	647	Comercial	undirected
56	9	19	Comercial	undirected	56	67	3043	Comercial	undirected
56	10	365	Comercial	undirected	56	68	886	Comercial	undirected
56	11	1350	Comercial	undirected	56	70	4272	Comercial	undirected
56	12	172	Comercial	undirected	56	71	366	Comercial	undirected
56	13	3410	Comercial	undirected	56	72	2228	Comercial	undirected
56	15	21	Comercial	undirected	56	74	997	Comercial	undirected
56	17	4	Comercial	undirected	56	77	364	Comercial	undirected
56	18	291	Comercial	undirected	56	78	720	Comercial	undirected
56	19	53	Comercial	undirected	56	80	6080	Comercial	undirected
56	22	2946	Comercial	undirected	56	82	574	Comercial	undirected
56	23	2268	Comercial	undirected	56	83	187	Comercial	undirected
56	24	79	Comercial	undirected	56	84	938	Comercial	undirected
56	25	400	Comercial	undirected	56	85	1869	Comercial	undirected
56	28	421	Comercial	undirected	56	86	145	Comercial	undirected
56	29	414	Comercial	undirected	56	87	3590	Comercial	undirected
56	30	1503	Comercial	undirected	56	88	2502	Comercial	undirected
56	31	15060	Comercial	undirected	56	89	233	Comercial	undirected
56	32	371	Comercial	undirected	56	90	1135	Comercial	undirected
56	34	295	Comercial	undirected	56	91	1625	Comercial	undirected
56	35	2635	Comercial	undirected	56	92	603	Comercial	undirected
56	36	656	Comercial	undirected	56	94	156	Comercial	undirected
56	38	574	Comercial	undirected	56	95	209	Comercial	undirected
56	39	1423	Comercial	undirected	48	33	122	Subidiary	undirected
56	41	814	Comercial	undirected	48	16	124	Subidiary	undirected
56	42	628	Comercial	undirected	48	40	33	Subidiary	undirected
56	43	300	Comercial	undirected	67	81	76	Subidiary	undirected
56	44	396	Comercial	undirected	67	73	119	Subidiary	undirected
56	45	300	Comercial	undirected	87	19	513	Subidiary	undirected
56	46	124	Comercial	undirected	87	21	29	Subidiary	undirected
56	47	38	Comercial	undirected	87	79	231	Subidiary	undirected
56	48	3732	Comercial	undirected	87	37	40	Subidiary	undirected
56	49	1055	Comercial	undirected	5	80	156	Comercial	undirected
56	50	1281	Comercial	undirected	88	80	156	Comercial	undirected
56	51	454	Comercial	undirected	31	57	156	Comercial	undirected
56	53	1626	Comercial	undirected	31	92	104	Comercial	undirected
56	54	678	Comercial	undirected	22	72	324	Comercial	undirected
56	55	90	Comercial	undirected	31	5	156	Comercial	Undirected
56	57	730	Comercial	undirected	31	68	156	Comercial	undirected
56	58	1330	Comercial	undirected	31	53	156	Comercial	undirected
56	60	29	Comercial	undirected					

Table A.11: Network in 2022, Nodes for A3

Id	Label	Id	Label	Id	Label
2	Andoas	31	CUZ	69	PIO

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Id	Label	Id	Label	Id	Label
4	ANS	33	El Estrecho	70	PIU
5	AQP	37	Galilea	73	Puerto Esperanza
7	ATA	40	Gueppi	75	RIJ
9	ATG	43	HUU	76	RIM
11	AYP	46	ILQ	79	San Lorenzo
14	Breu	48	IQT	81	Sepahua
16	Caballococha	49	JAE	84	TBP
19	CHH	50	JAU	85	TCQ
20	CHM	52	JJI	86	TGI
21	Ciro Alegria	53	JUL	87	TPP
22	CIX	56	LIM	88	TRU
23	CJA	59	Maria Reiche Neuman	90	TYL
26	Contamana	67	PCL	93	YMS
27	Colonia de Angamos	68	PEM		

Table A.12: Network in 2022, Links for A3

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
56	2	0	No Comercial	undirected	56	68	886	Comercial	undirected
56	4	50	Comercial	undirected	56	69	0	No Comercial	undirected
56	5	7030	Comercial	undirected	56	70	4272	Comercial	undirected
56	7	39	Comercial	undirected	56	73	0	No Comercial	undirected
56	9	19	Comercial	undirected	56	75	0	No Comercial	undirected
56	11	1350	Comercial	undirected	56	76	0	No Comercial	undirected
56	14	0	No Comercial	undirected	56	79	0	No Comercial	undirected
56	16	0	No Comercial	undirected	56	81	0	No Comercial	undirected
56	19	53	Comercial	undirected	56	84	938	Comercial	undirected
56	20	0	No Comercial	undirected	56	85	1869	Comercial	undirected
56	21	0	No Comercial	undirected	56	86	145	Comercial	undirected
56	22	2946	Comercial	undirected	56	87	3590	Comercial	undirected
56	23	2268	Comercial	undirected	56	88	2502	Comercial	undirected
56	26	0	No Comercial	undirected	56	90	1135	Comercial	undirected
56	27	0	No Comercial	undirected	56	93	0	No Comercial	undirected
56	31	15060	Comercial	undirected	48	33	122	Subdiary	undirected
56	33	0	No Comercial	undirected	48	16	124	Subdiary	undirected
56	37	0	No Comercial	undirected	48	27	0	Subdiary	undirected
56	40	0	No Comercial	undirected	48	40	33	Subdiary	undirected
56	43	300	Comercial	undirected	67	14	0	Subdiary	undirected
56	46	124	Comercial	undirected	67	81	76	Subdiary	undirected
56	48	3732	Comercial	undirected	67	73	119	Subdiary	undirected
56	49	1055	Comercial	undirected	87	19	513	Subdiary	undirected
56	50	1281	Comercial	undirected	87	21	29	Subdiary	undirected
56	52	0	No Comercial	undirected	87	79	231	Subdiary	undirected
56	53	1626	Comercial	undirected	87	37	40	Subdiary	undirected
56	56	0	No Comercial	undirected	31	5	156	Comercial	Undirected
56	59	0	No Comercial	undirected	31	68	156	Comercial	undirected
56	67	3043	Comercial	undirected	31	53	156	Comercial	undirected

Table A.13: Network in 2026, Nodes for A2

Id	Label	Id	Label	Id	Label
1	AEP	32	EZE	60	PCL
2	AMS	33	FLL	61	PEM
4	ANF	34	Galilea	63	PIS
6	AQP	35	GIG	64	PIU
7	ASU	36	GRU	65	POA
10	ATL	37	Gueppi	66	PTY
11	AYP	38	GYE	67	Puerto Esperanza
12	BOG	39	HUU	68	PUJ
13	Breu	40	IAH	71	SAL
14	Caballococha	41	ILQ	72	San Lorenzo
15	CDG	42	IQT	73	SCL
16	CGL	43	JAE	74	SDQ
17	CHH	44	JAU	75	Sepahua
18	CHM	45	JFK	76	SJO
19	Ciro Alegria	47	JUL	77	TBP
20	CIX	48	LAX	78	TCQ
21	CJA	49	LIM	79	TGI
22	CLO	50	LPB	80	TPP
24	Colonia de Angamos	51	MAD	81	TRU
25	COR	53	MCO	82	TYL
26	CTG	54	MDE	83	UIO
27	CUN	55	MDZ	84	VVI
28	CUZ	56	MEX	86	YUL
29	DFW	57	MIA	87	YYZ
30	El Estrecho	58	MVD		
31	EWR	59	MZA		

Table A.14: Network in 2026, Links for A2

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
49	1	156	Comercial	undirected	49	65	78	Comercial	undirected
49	2	347	Comercial	undirected	49	66	517	Comercial	undirected
49	4	17	Comercial	undirected	49	68	736	Comercial	undirected
49	6	5555	Comercial	undirected	49	71	59	Comercial	undirected
49	7	186	Comercial	undirected	49	73	837	Comercial	undirected
49	10	365	Comercial	undirected	49	74	43	Comercial	undirected
49	11	1188	Comercial	undirected	49	76	362	Comercial	undirected
49	12	646	Comercial	undirected	49	77	1376	Comercial	undirected
49	15	276	Comercial	undirected	49	78	1342	Comercial	undirected
49	16	82	Comercial	undirected	49	79	52	Comercial	undirected
49	17	159	Comercial	undirected	49	80	3294	Comercial	undirected
49	18	23	Comercial	undirected	49	81	2484	Comercial	undirected
49	20	2158	Comercial	undirected	49	82	1034	Comercial	undirected
49	21	1830	Comercial	undirected	49	83	437	Comercial	undirected
49	22	79	Comercial	undirected	49	84	459	Comercial	undirected
49	25	186	Comercial	undirected	49	86	13	Comercial	undirected
49	26	144	Comercial	undirected	49	87	19	Comercial	undirected
49	27	1311	Comercial	undirected	42	30	142	Subsidiary	undirected
49	28	9979	Comercial	undirected	42	14	142	Subsidiary	undirected
49	29	306	Comercial	undirected	42	24	82	Subsidiary	undirected
49	31	42	Comercial	undirected	42	37	67	Subsidiary	undirected

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Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
49	32	636	Comercial	undirected	60	13	185	Subsidiary	undirected
49	33	717	Comercial	undirected	60	75	164	Subsidiary	undirected
49	35	141	Comercial	undirected	60	67	303	Subsidiary	undirected
49	36	184	Comercial	undirected	80	17	204	Subsidiary	undirected
49	38	338	Comercial	undirected	80	19	27	Subsidiary	undirected
49	39	1456	Comercial	undirected	80	72	60	Subsidiary	undirected
49	40	365	Comercial	undirected	80	34	18	Subsidiary	undirected
49	41	74	Comercial	undirected	28	12	1936	Comercial	undirected
49	42	2612	Comercial	undirected	28	73	2509	Comercial	undirected
49	43	577	Comercial	undirected	28	66	1550	Comercial	undirected
49	44	884	Comercial	undirected	28	57	1380	Comercial	undirected
49	45	364	Comercial	undirected	28	32	636	Comercial	undirected
49	47	1938	Comercial	undirected	28	1	468	Comercial	undirected
49	48	377	Comercial	undirected	28	56	1021	Comercial	undirected
49	50	58	Comercial	undirected	28	36	552	Comercial	undirected
49	51	1212	Comercial	undirected	28	50	174	Comercial	undirected
49	53	108	Comercial	undirected	28	61	156	Comercial	undirected
49	54	594	Comercial	undirected	28	6	156	Comercial	undirected
49	55	27	Comercial	undirected	28	47	156	Comercial	undirected
49	56	341	Comercial	undirected	28	42	156	Comercial	undirected
49	57	460	Comercial	undirected	81	73	156	Comercial	undirected
49	58	207	Comercial	undirected	20	66	324	Comercial	undirected
49	59	108	Comercial	undirected	28	11	104	Comercial	undirected
49	60	2256	Comercial	undirected	6	73	156	Comercial	undirected
49	61	1097	Comercial	undirected	81	73	156	Comercial	undirected
49	63	202	Comercial	undirected	28	84	156	Comercial	undirected
49	64	3374	Comercial	undirected	42	60	104	Comercial	undirected
42	80	104	Comercial	undirected					

Table A.15: Network in 2026, Nodes for A3

Id	Label	Id	Label	Id	Label
3	Andoas	28	CUZ	62	PIO
5	ANS	30	El Estrecho	64	PIU
6	AQP	34	Galilea	67	Puerto Esperanza
8	ATA	37	Gueppi	69	RIJ
9	Atalaya	39	HUU	70	RIM
11	AYP	41	ILQ	72	San Lorenzo
13	Breu	42	IQT	75	Sepahua
14	Caballococha	43	JAE	77	TBP
17	CHH	44	JAU	78	TCQ
18	CHM	46	JJI	79	TGI
19	Ciro Alegria	47	JUL	80	TPP
20	CIX	49	LIM	81	TRU
21	CJA	52	Maria Reiche Neuman	82	TYL
23	Contamana	60	PCL	85	YMS
24	Colonia de Angamos	61	PEM		

Table A.16: Network in 2026, Links for A3

Source	Target	Weight	Label	Type	Source	Target	Weight	Label	Type
49	3	0	No Comercial	undirected	49	64	3374	Comercial	undirected
49	5	0	No Comercial	undirected	49	67	0	No Comercial	undirected
49	6	5555	Comercial	undirected	49	69	0	No Comercial	undirected
49	8	0	No Comercial	undirected	49	70	0	No Comercial	undirected
49	9	0	No Comercial	undirected	49	72	0	No Comercial	undirected
49	11	1188	Comercial	undirected	49	75	0	No Comercial	undirected
49	13	0	No Comercial	undirected	49	77	1376	Comercial	undirected
49	14	0	No Comercial	undirected	49	78	1342	Comercial	undirected
49	17	159	Comercial	undirected	49	79	52	Comercial	undirected
49	18	23	Comercial	undirected	49	80	3294	Comercial	undirected
49	19	0	No Comercial	undirected	49	81	2484	Comercial	undirected
49	20	2158	Comercial	undirected	49	82	1034	Comercial	undirected
49	21	1830	Comercial	undirected	49	85	0	No Comercial	undirected
49	23	0	No Comercial	undirected	42	30	142	Subsidiary	undirected
49	24	0	No Comercial	undirected	42	14	142	Subsidiary	undirected
49	28	9979	Comercial	undirected	42	24	82	Subsidiary	undirected
49	30	0	No Comercial	undirected	42	37	67	Subsidiary	undirected
49	34	0	No Comercial	undirected	60	13	185	Subsidiary	undirected
49	37	0	No Comercial	undirected	60	75	164	Subsidiary	undirected
49	39	1456	Comercial	undirected	60	67	303	Subsidiary	undirected
49	41	74	Comercial	undirected	80	17	204	Subsidiary	undirected
49	42	2612	Comercial	undirected	80	19	27	Subsidiary	undirected
49	43	577	Comercial	undirected	80	72	60	Subsidiary	undirected
49	44	884	Comercial	undirected	80	34	18	Subsidiary	undirected
49	46	0	No Comercial	undirected	28	6	156	Comercial	undirected
49	47	1938	Comercial	undirected	28	61	156	Comercial	undirected
49	49	0	No Comercial	undirected	28	47	156	Comercial	undirected
49	52	0	No Comercial	undirected	28	42	156	Comercial	undirected
49	60	2256	Comercial	undirected	42	80	104	Comercial	undirected
49	61	1097	Comercial	undirected	42	60	104	Comercial	undirected
49	62	0	No Comercial	undirected	28	11	104	Comercial	undirected

## Appendix B

### Public Airfields Authorized for Peruvian CAA

N°	Type	Airport	Ident.	Department	Operator	Owner	Hierarchy	Analysed
1	Airport	Chachapoyas	CHH	Amazonas	Aeropuertos del Perú S.A.	Concessioned	National	YES
2	Aerodrome	Ciro Alegria		Amazonas	Corpac S.A.	Government	Regional	YES
3	Aerodrome	Galilea		Amazonas	Corpac S.A.	Government	Regional	YES
4	Airport	Rodríguez de Mendoza	RIM	Amazonas	Corpac S.A.	Government	Regional	YES
5	Airport	Tnte.FAP Jaime A. de Montreuil Morales	CHM	Ancash	Corpac S.A.	Government	National	YES
6	Airport	Huascarán (Anta - Huaraz)	ATA	Ancash	Aeropuertos del Perú S.A.	Concessioned	National	YES
7	Airport	Andahuaylas	ANS	Apurimac	Corpac S.A.	Government	National	YES
8	International Airport	Alfredo Rodríguez Ballón	AQP	Arequipa	Aeropuertos Andinos del Perú S.A.	Concessioned	National	YES
9	Aerodrome	Mollendo		Arequipa	Provincial Municipality of Islay	Government		NO
10	Airport	Cml.FAP Alfredo Mendivil	AYP	Ayacucho	Aeropuertos Andinos del Perú S.A.	Concessioned	National	YES
11	Aerodrome	Palmapampa		Ayacucho	Peruvian National Police	Government		NO
12	Aerodrome	Vilcashuaman		Ayacucho	Corpac S.A.	Government	Local	NO
13	Airport	May.Gral.FAP Armando Revoredo Iglesias	CJA	Cajamarca	Aeropuertos del Perú S.A.	Concessioned	National	YES
14	Airport	Jaén	JAE	Cajamarca	Corpac S.A.	Government	National	YES
15	International Airport	Tnte.FAP Alejandro Velasco Astete	CUZ	Cusco	Corpac S.A.	Government	National	YES
16	Aerodrome	Patria		Cusco	Corpac S.A.	Government	Local	NO
17	Aerodrome	Yauri		Cusco	Provincial Municipality of Espinar	Government	Local	NO
18	Airport	Alf.FAP David Figueroa Femandini	HUU	Huánuco	Corpac S.A.	Government	National	YES
19	Aerodrome	Pueblo Libre de Codo		Huánuco	Agencia Municipal de Pueblo Libre de Codo	Government	Local	NO
20	Airport	Tingo Maria	TGI	Huánuco	Corpac S.A.	Government	National	YES
21	Aerodrome	María Reiche Neuman		Ica	Corpac S.A.	Government	Local	YES
22	International Airport	Pisco	PIO	Ica	Aeropuertos del Perú S.A.	Concessioned	National	YES
23	Aerodrome	Cutivireni		Junin	Comunidad Nativa de Cutivireni	Government		NO
24	Airport	Jauja	JAU	Junin	Corpac S.A.	Government	National	YES
25	Aerodrome	May.PNP Nancy Flores Paucar		Junin	Corpac S.A.	Government	Regional	NO
26	Aerodrome	Huamachuco		La Libertad	Provincial Municipality of Sánchez Carrión	Government	Local	NO
27	International Airport	Cap. Carlos Martínez de Pinillos	TRU	La Libertad	Aeropuertos del Perú S.A.	Concessioned	National	YES
28	Aerodrome	Tulpo		La Libertad	District Municipality of Mollebamba	Government	Local	NO
29	Aerodrome	Urpay		La Libertad	District Municipality of Urpay	Government	Local	NO
30	International Airport	Cap.FAP José Abelardo Quiñones Gonzales	CIX	Lambayeque	Aeropuertos del Perú S.A.	Concessioned	National	YES
31	International Airport	Internacional Jorge Chávez	LIM	Lima	Lima Airport Partners S.R.L.	Concessioned	National	YES
32	Aerodrome	Bellavista		Loreto	Comunidad de Bellavista	Government		NO
33	Aerodrome	Buncuyo		Loreto	Comunidad de Buncuyo	Government		NO
34	Aerodrome	Cabalococha		Loreto	Corpac S.A.	Government	Regional	YES

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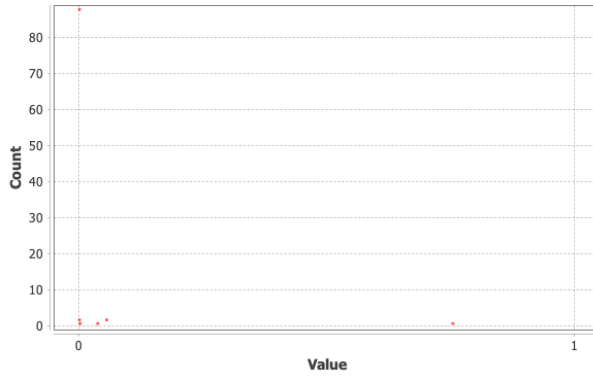
Nº	Type	Airport	Ident.	Department	Operator	Owner	Hierarchy	Analysed
35	Aerodrome	Colonia Angamos		Loreto	District Municipality of Yaquerana	Government	Local	YES
36	Aerodrome	Contamana		Loreto	Gobierno Regional de Loreto	Government	Local	YES
37	Aerodrome	El Estrecho		Loreto	Corpac S.A.	Government		YES
38	Aerodrome	Gueppi		Loreto	Corpac S.A.	Government		YES
39	International Airport	CrnI.FAP Francisco Secada Vignetta	IQT	Loreto	Aeropuertos del Perú S.A.	Concessioned	National	YES
40	Aerodrome	Orellana		Loreto	District Municipality of Vargas Guerra	Government	Local	NO
41	Aerodrome	Pampa Hermosa		Loreto	Corpac S.A.	Government	Local	NO
42	Aerodrome	San Lorenzo		Loreto	Provincial Municipality of Datem del Marañón	Government	Local	YES
43	Airport	Moisés Benzaquén Rengifo	YMS	Loreto	Corpac S.A.	Government	National	YES
44	Aerodrome	Iñapari		Madre de Dios	Corpac S.A.	Government	Regional	NO
45	Airport	Padre Aldamiz	PEM	Madre de Dios	Aeropuertos Andinos del Perú S.A.	Concessioned	National	YES
46	Airport	Ilo		Moquegua	Corpac S.A.	Government	National	YES
47	Aerodrome	Aerodromo de Moquegua	ILQ	Moquegua	Corpac S.A.	Government		NO
48	Aerodrome	Ciudad Constitución		Pasco	District Municipality of Puerto Bermudez	Government	Local	NO
49	Aerodrome	Vicco		Pasco	District Municipality of Vicco	Government	Local	NO
50	Airport	Cap.FAP Guillermo Concha Iberico	PIU	Piura	Aeropuertos del Perú S.A.	Concessioned	National	YES
51	Aerodrome	Huancabamba		Piura	Provincial Municipality of Huancabamba	Government	Local	NO
52	International Airport	Cap.FAP Victor Montes	TYL	Piura	Aeropuertos del Perú S.A.	Concessioned	National	YES
53	International Airport	Inca Manco Capac	JUL	Puno	Aeropuertos Andinos del Perú S.A.	Concessioned	National	YES
54	Airport	Juanjui	JJI	San Martín	Corpac S.A.	Government	Regional	YES
55	Airport	Rioja	RIJ	San Martín	Corpac S.A.	Government	National	YES
56	Aerodrome	Saposoa		San Martín	Corpac S.A.	Government	Regional	NO
57	Airport	Cadete FAP Guillermo del Castillo Paredes	TPP	San Martín	Aeropuertos del Perú S.A.	Concessioned	National	YES
58	Aerodrome	Tocache		San Martín	Corpac S.A.	Government	Regional	NO
59	International Airport	CrnI.FAP Carlos Ciriani Santa Rosa	TCQ	Tacna	Aeropuertos Andinos del Perú S.A.	Concessioned	National	YES
60	Airport	Cap.FAP Pedro Canga Rodríguez	TBP	Tumbes	Aeropuertos del Perú S.A.	Concessioned	National	YES
61	Aerodrome	Atalaya		Ucayali	Corpac S.A.	Government	Regional	YES
62	Aerodrome	Breu		Ucayali	Corpac S.A.	Government	Local	YES
63	Aerodrome	Paititi		Ucayali	Paititi Community	Government		NO
64	International Airport	Cap.FAP David Armando Abensur Rengifo	PCL	Ucayali	Aeropuertos del Perú S.A.	Concessioned	National	YES
65	Aerodrome	Puerto Esperanza		Ucayali	Corpac S.A.	Government		YES
66	Aerodrome	Sepahua		Ucayali	District Municipality of Sepahua	Government	Local	YES



# Appendix C

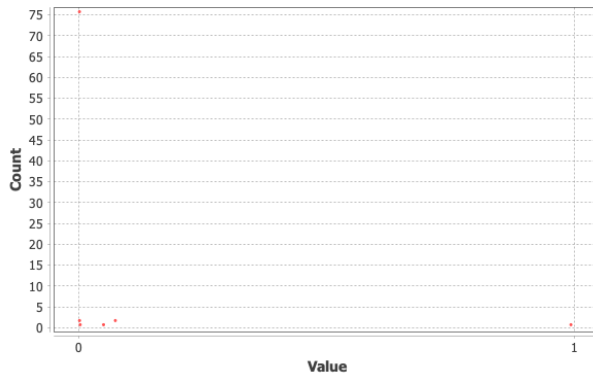
## Software Output

**Betweenness Centrality Distribution**



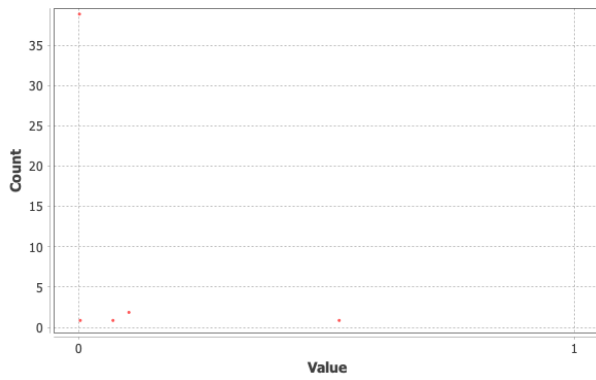
(a) *A1*

**Betweenness Centrality Distribution**



(b) *A2*

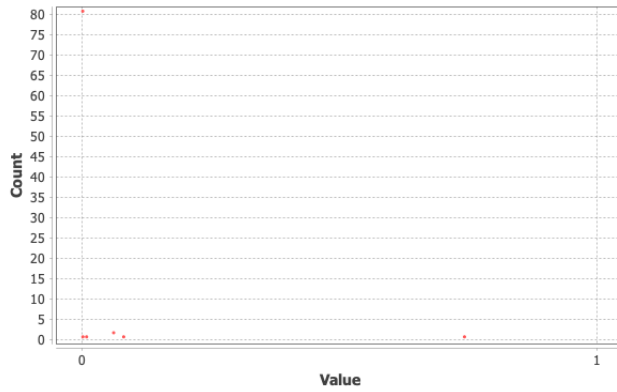
**Betweenness Centrality Distribution**



(c) *A3*

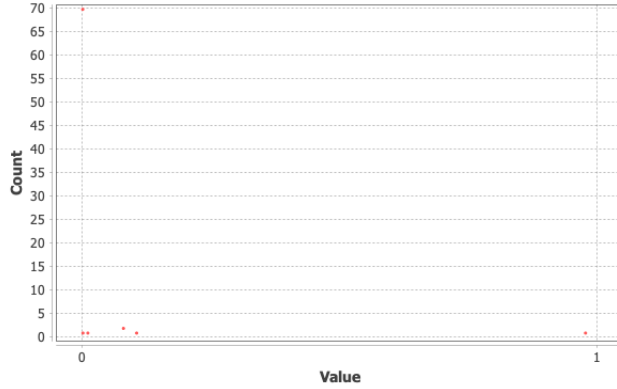
Figure C.1: Betweenness Centrality Distribution in 2019

**Betweenness Centrality Distribution**



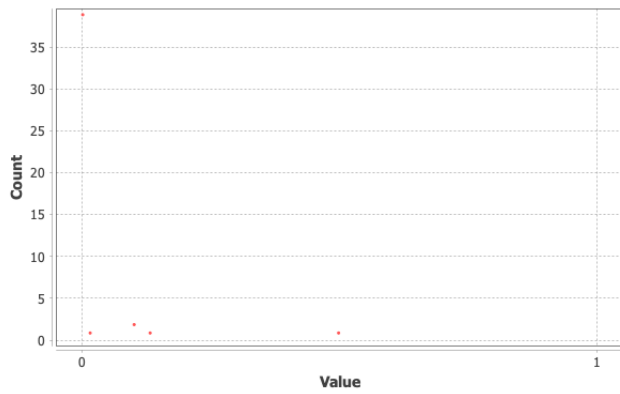
(a) *A1*

**Betweenness Centrality Distribution**



(b) *A2*

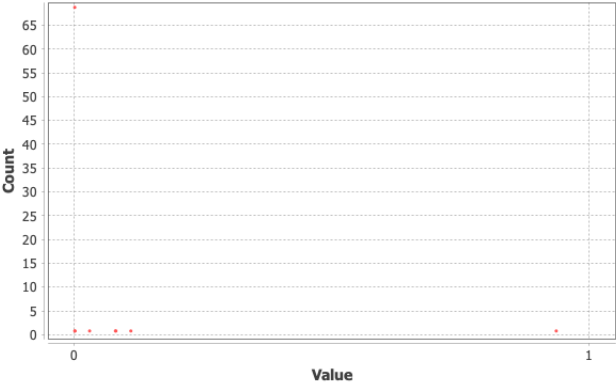
**Betweenness Centrality Distribution**



(c) *A3*

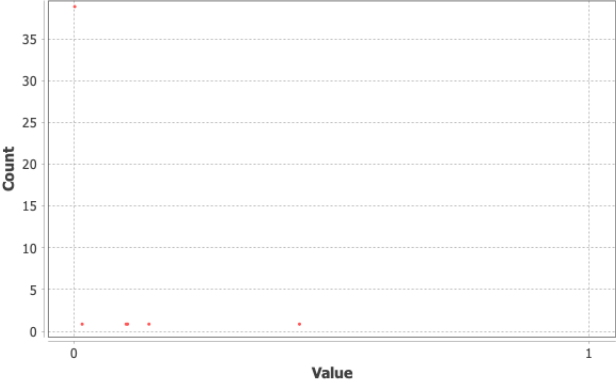
Figure C.2: Betweenness Centrality Distribution in 2022

**Betweenness Centrality Distribution**



(a) A2

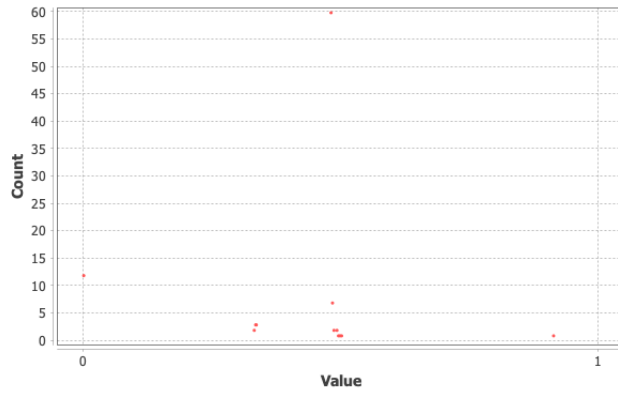
**Betweenness Centrality Distribution**



(b) A3

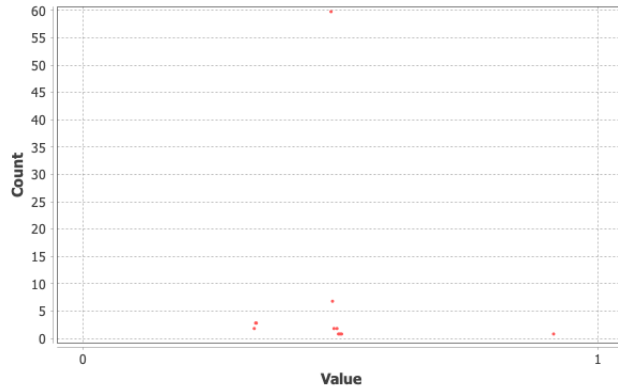
Figure C.3: Betweenness Centrality Distribution in 2026

**Closeness Centrality Distribution**



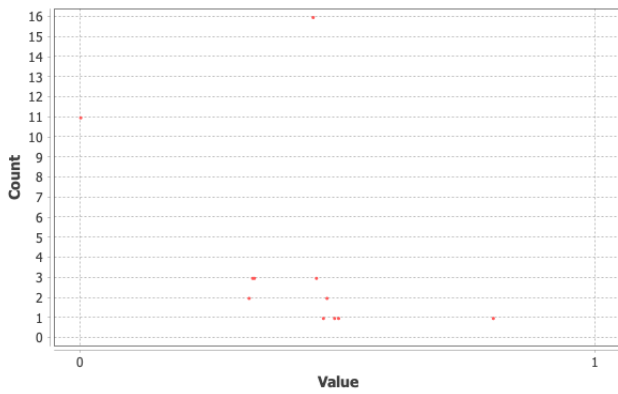
(a) A1

**Closeness Centrality Distribution**



(b) A2

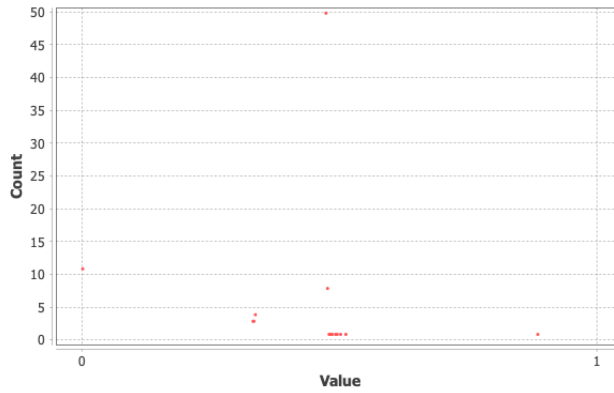
**Closeness Centrality Distribution**



(c) A3

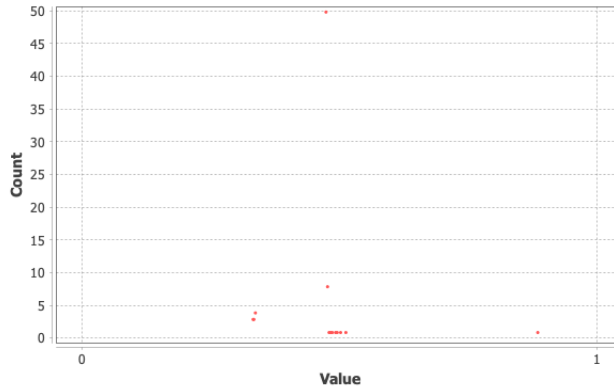
Figure C.4: Closeness Centrality Distribution in 2019

**Closeness Centrality Distribution**



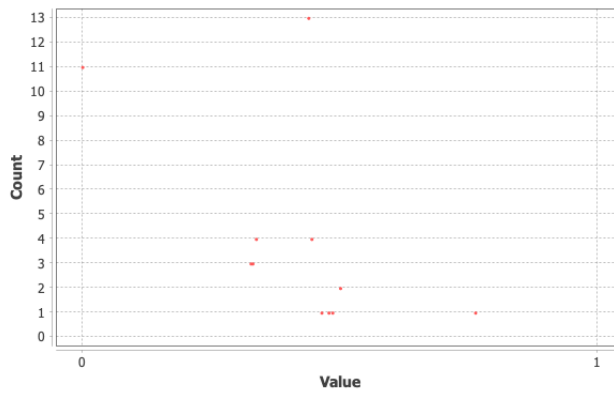
(a) *A1*

**Closeness Centrality Distribution**



(b) *A2*

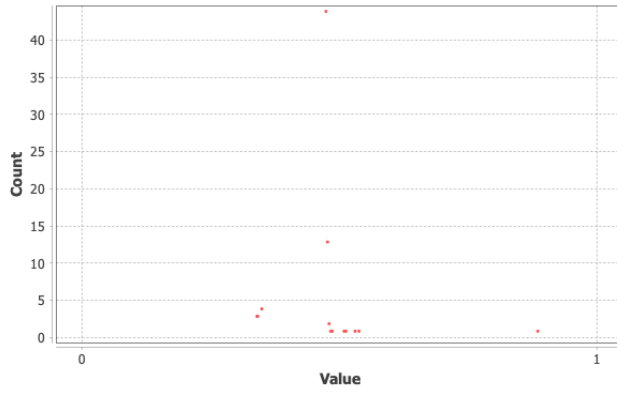
**Closeness Centrality Distribution**



(c) *A3*

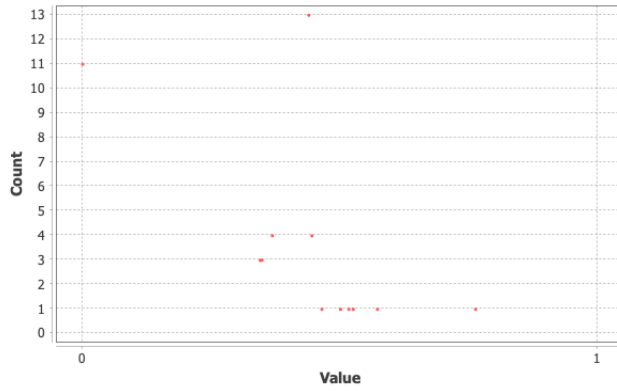
Figure C.5: Closeness Centrality Distribution in 2022

**Closeness Centrality Distribution**



(a) A2 (2026)

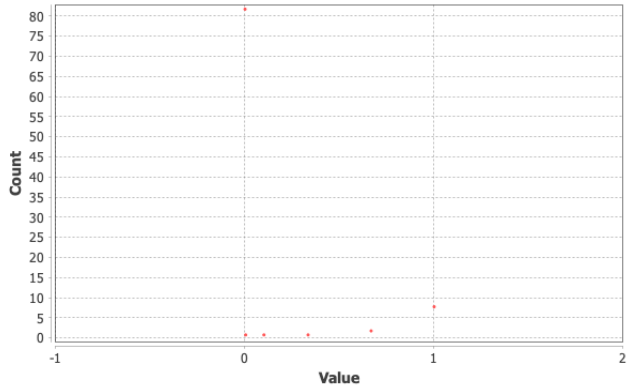
**Closeness Centrality Distribution**



(b) A3

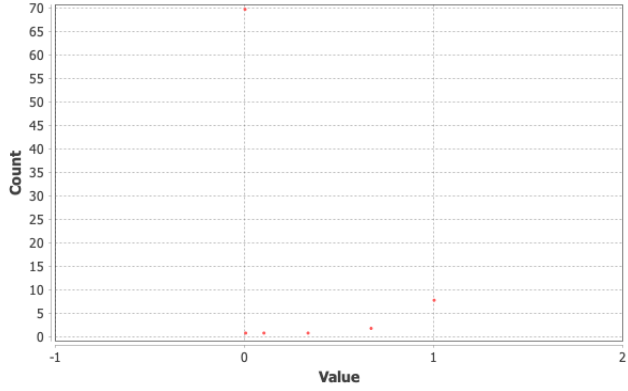
Figure C.6: Closeness Centrality Distribution in 2026

**Clustering Coefficient Distribution**



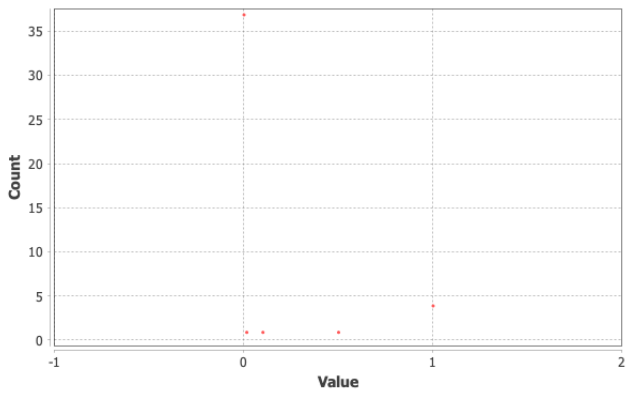
(a) *A1*

**Clustering Coefficient Distribution**



(b) *A2*

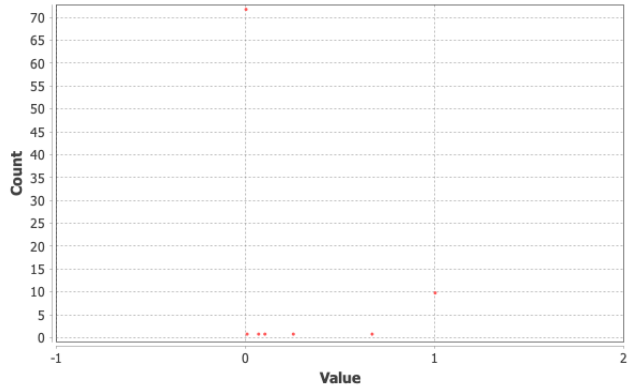
**Clustering Coefficient Distribution**



(c) *A3*

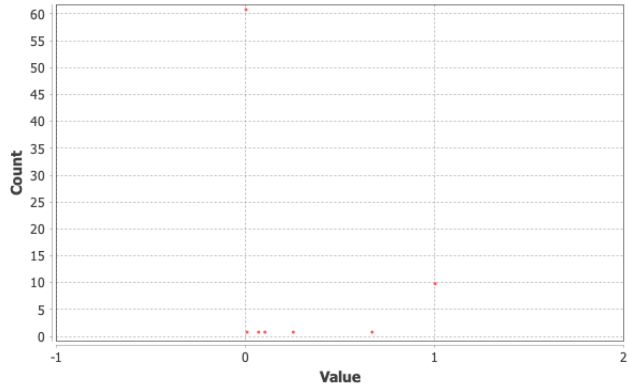
Figure C.7: Clustering Coefficient in 2019

**Clustering Coefficient Distribution**



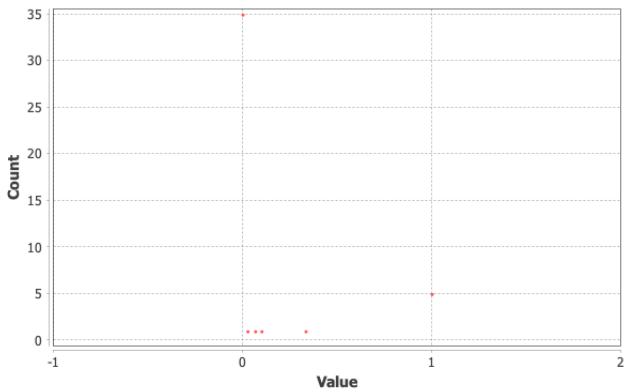
(a) A1

**Clustering Coefficient Distribution**



(b) A2

**Clustering Coefficient Distribution**

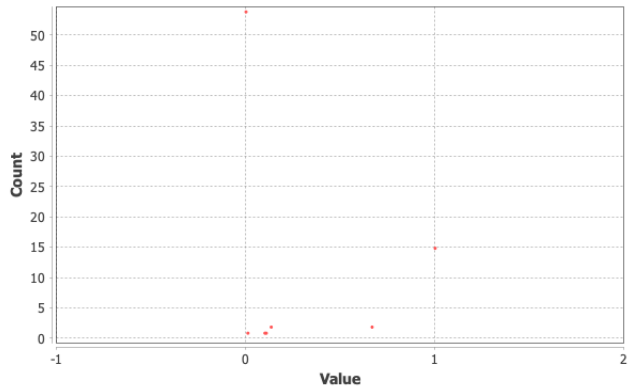


(c) A3

Figure C.8: Clustering Coefficient in 2022

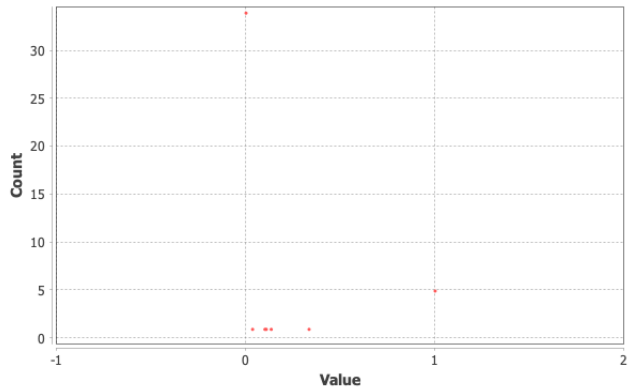


**Clustering Coefficient Distribution**



(a) A2

**Clustering Coefficient Distribution**



(b) A3

Figure C.9: Clustering Coefficient in 2026