The Effects of Airlines and Borders on the Transmission of SARS-CoV-2 in the EU

Group 9: [redacted], [redacted], Ahmad Kamar

Carleton University

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Introduction

COVID-19 is an infectious disease caused by the SARS-CoV-2 virus [1]. Originally found in Wuhan, China in late 2019, the disease became epidemic and quickly spread past the Hubei province where Wuhan was located. The expansion of the airline business has made airlines a vital mode for transportation, business, and travel; however, the rapid access to international travel has also increased the potential for a global health crisis [13]. By April 2020, COVID-19 was contained locally but quickly became a pandemic with over 100 countries reporting emerging cases [2]. The R_0 (R naught) is the basic reproduction ratio used by epidemiologists to measure the transmibillity of a virus [7]. Having $R_0 < 1$ means the disease will eventually perish, and $R_0 > 1$ will mean the disease will continue to spread and potentially cause an epidemic. Using contact tracing, the World Health Organization (WHO) estimated the R_0 of COVID-19 to be between 1.4 and 2.4 [7]. Becoming infected with COVID-19 also results in respiratory illness that may range from mild to deadly; especially deadly for older individuals and those with pre-existing medical conditions [1]. The result of severe respiratory illness has led to a worldwide shortage of hospital beds as well, resulting in measures to not overwhelm health systems around the world [3]. To combat the spread of the virus and an overtaxed health structure, governments around the world have taken costly measures. To explain, many countries around the world have introduced lockdowns with strong containment procedures for citizens and businesses for the first time in history [3]. Governments also introduced requirements such as social distancing and masks. Testing, tracing, and isolation were key parts of containing and measuring the early pandemic before the introduction of vaccine measures. Studying and understanding the spread of COVID-19 is necessary and important as the impact of the pandemic has been severe on governments around the world. The COVID-19 global lockdowns have drastically impacted the world economy. For example, governments have faced excess spending and reduced revenue, increasing their overall deficits and debt [3]. The impact of COVID-19 has also led to food and medication shortages in various countries [3]. Understanding the spread of the virus is key for future planning as emerging variants such as B.1.1.529, a strain first identified in South Africa and also known as Omicron, continuously spread between countries, leading to more lockdowns and constant restrictions [4]. With Omicron's rapid spread, the European Centre for Disease Prevention and Control made a statement saying that mathematical models indicate that Omicron could become the dominant strain of COVID-19 in the European Union (EU) [8].

The European Union is a political union between 27 member states located within Europe [5] and will be the region where we investigate the spread of COVID-19. The EU poses as an interesting region to study due to their free border controls. All European Union citizens can freely travel throughout most of the continent after the abolishment of border controls between the member states [5], which may influence how COVID-19 will spread. Since the member states are closely connected with each other, the multiple free borders each country can share also makes the EU an intriguing case study on the early transmission of COVID-19. Many

European countries also have numerous airports. Some researchers predict the risk of disease spread is based on the geographical distance of the airport connection network of various countries [13], making the EU an engaging region to study the spread of COVID-19.

With the first cases being reported in France [6], infected people traveling through free borders and airlines could have played a role in spreading throughout the union before the pandemic was officially declared by health officials. Understanding the transmission of the virus, we pose our research question: how do airlines and borders affect transmission of SARS-CoV-2 in the EU? To examine this research question we will be analyzing data sets to understand the role interborder travel has had on the spread of the virus. We will also investigate if border restrictions can play a role in stopping or slowing down the pandemic. We hypothesize that countries or airlines with higher betweenness will be more likely to catch and spread covid. We also hypothesize that countries or airlines that are clustered or have a higher clustering coefficient will spread more of the virus. Our final hypothesis is that countries with high degrees will have a high rate of infections due to the number of connections it has to other nations. This study may give insight to the hypothesis that a country that borders many other nations will be more susceptible to the spread of the disease. This research question plays an important role as the results will demonstrate if the border control measures taken by the EU were effective in slowing the spread of COVID-19.

Related Works

COVID-19 spreading through a network has been a topic investigated by academics. For example, Firth et al (2020) simulated a COVID-19 outbreak within a social network [9]. The paper focused on COVID-19 spreading through a social network within the town of Halsmere, United Kingdom under different control scenarios. The network consisted of 468 individuals with 1,257 social links weighted by 1,616 daily contacts and a single infector. The epidemic model showed that uncontrolled outbreaks in Haslemere from a single infection resulted in 75% of the population being infected after 70 days. The study also showed isolation of individuals when they became symptomatic resulted in 66% of the population becoming infected. Primary contact tracing resulted in 48% infected and secondary contact tracing resulted in 16% of the population being infected after 70 days, with both forms of contact tracing requiring high portions, a median of 43%, of individuals to be isolated.

To figure out how borders play a role in the pandemic, researchers have investigated border controls between European member states and its effect on the spread of COVID-19. Eckardt et al (2020) found that border controls helped contain COVID-19 but only for regions with substantial numbers of cross-border commuters prior to the pandemic [10]. By using a Bayesian inference with an INLA formalism to take the unobserved spatio-temporal heterogeneity (e.g time-varying local policies) of the data into account, the researchers found border controls had a 6% effect on the cases of COVID-19 [10].

The relationship between COVID-19 and airlines within the EU has also been a topic explored by scholars. For example, Liu et al (2021) has looked at the interrelationship between the spread of the COVID-19 pandemic and the frequency of flights within the EU [11]. The paper analyzed the causal impact of travel restrictions on flights and its effect on the spread of COVID-19. They found that reduced flight frequency had a spillover effect on confirmed cases within neighboring countries. A reduction in flights by 1% reduced the number of confirmed COVID-19 cases by 0.431% according to their two-stage spatial Durbin model and by 0.908% through their counterfactual analysis. The number of people infected within Europe was around 2.1 million by May 2020. Following the first lockdowns in March 2020, certain European countries canceled 795,000 flights which could have saved up to six million people from becoming infected and 101,309 lives. The causal relationship between travel restrictions and flight frequency, and further, its consequential impact on COVID-19 across European countries has been demonstrated through this study.

Although researchers have investigated COVID-19 spread in a network, borders, and airlines, the research does not investigate the spread of virus through the EU network. We hope to investigate how COVID-19, which was initially found in the European nation of France, will spread through a border and airline network. We also hope our work can shed light on the role clustering of countries plays for the spread of COVID-19.

Background

A common task in graph and network theory is to establish a node's in and out degrees. The indegree represents the number of incoming edges from other nodes while the outdegree indicates the amount of outgoing edges from the node in question to other nodes within the graph. For our paper, this could relate to the number of incoming flights a city has and the number of flights departing from there. This could also lead to us discovering which cities are more popular and thus more frequented by various people. [source: Lecture 2: Network Science and Graphs]

Node and edge blocking is an additional concept worth noting as our project leans into the idea of removing some flights from the EU flight map. This would be an example of edge blocking as we are removing an edge from the graph. We could also consider a complete lockdown in one country as node blocking since it would remove the node from having any connections to other nodes in the graph.

The next concept is triadic closures. Triadic closures occur when two nodes who are not connected, have a mutual connection to another node. This creates a scenario where the unconnected nodes are more likely to form a connection to their mutual friend. This also creates a more densely connected graph as it initiates more edges to be formed. This concept leads into another which is clustering coefficients. This property measures the fraction of pairs of a node's connections that are also connected to each other with direct edges. [source: Lecture 3: Strong Ties and Weak Ties]

Another networking theory that can affect graphs is cascading. Cascading occurs when nodes influence their connections to follow the same pattern as them. This could be related to our work as COVID-19 spreads from node to node via connected edges. [source: Lecture 13: Cascades]

More graph theory concepts that may come into play for this paper are strong connections as well as strongly connected components. A directed graph is strongly connected if all vertices are accessible from each vertex. A strongly connected component is a subgraph of the main graph that is strongly connected. [source: Lecture 11: Web Structure and Search]

A general phenomenon in graph theory is understanding that networks can evolve over time. Graphs that are time reliant will change gradually, possibly by adding more edges and nodes, or even losing some edges and nodes. As this project will include the observation of data taken months apart, the graphs involved are evolved networks.

As this is a topic involving probability, normal distribution should be touched on as well. In a graph, the normal distribution appears similar to a bell curve where the bump represents the more frequent and higher probability. This bump is typically in the middle, but can be skewed to either left or right.

Data

Due to the large-scale impacts of the COVID-19 pandemic, this paper will make use of the various datasets that are being collected by organizations to research COVID-19's global spread.

This paper examines the Coronavirus Cases dataset by Our World in Data, which is an online publication that focuses on large global problems such as poverty, disease, and war [12]. The dataset looks at confirmed cases country-by-country, allowing us to examine a country's total caseload [16]. The dataset also includes daily cases, new and total deaths, ICU patients, tests administered, vaccinations, and more. Nevertheless, this paper will mainly focus on the daily and total cases to investigate the effects of airlines and borders on the spread of COVID-19. The data presented is collected daily; however, some countries do not provide daily updates to their cases so we will look at a rolling average of cases over a 7-day period to compare the spread of COVID-19 by week in different member states. The dataset provides cases for every country, so we will be filtering the data as well to only examine the 27 countries within the

European Union. We will also use the available population data provided to calculate COVID-19 cases per 1000 members of the population within each member state.

To examine the effects airline travel within each country, we will have to investigate airport and flight datasets. We will be examining the Airports dataset by OurAirports, which is an online resource of global aviation data [15]. The dataset lists every airport globally, along with their region code, continent, and airport size. We will be filtering airports to only examine those that exist within the European Union.

We will also make use of the COVID-19 Flight Dataset by Opensky [14]. The dataset provides information on flights that connect between individual airports, where we will apply the flights to airports strictly within the EU. We will also investigate airlines and airports around the world to see if any similar pattern can be found pre and post the COVID-19 pandemic.

Model

The spread of COVID-19 through borders and airlines within the EU can be modeled by networks. To examine our research question, how airlines and borders affect transmission of SARS-CoV-2 in the EU, we will be constructing two styles of networks: a border network and an airline network.

The first network will consist of all the border connections within the European Union. The nodes will be the countries within the EU. The edges will be any borders a country shares. To construct the network, we will track which country shares borders. To understand the role borders play, we will investigate the betweenness of all land bordered nations. We will also investigate the clustering of the countries using each country's clustering coefficient. The degrees of the nodes will be observed as well since it plays a part in our hypothesis that countries with higher degrees will have a higher transmission rate due to the higher number of surrounding influences.

The second network will contain all IATA (International Air Transport Association) airports and airlines within the EU. The nodes will be airports that exist within a country and will be color coded according to their country. The edges will be connecting flights between the airports. To investigate the relationship between COVID-19 and inter-country flights, we will examine the betweenness of our airport network. We will also look into the clustering of airports to see if it has a relationship to COVID-19 cases.

Attributes that will be tracked include the number of nodes and their degrees, number of edges. We also hope to see noticeable patterns in the graphs that resemble concepts such as the bow-tie structure of the web and its strongly connected components [17].

The formal problem we will try to solve is, how can we apply networking/graph theory to this scenario and further extrapolate the data to answer our hypotheses. We are looking to see if the clustering coefficient has a connection to the speed at which countries spread the virus to neighboring countries. Another theory that will be used is centrality betweenness in hopes of finding the key nodes based on how many shortest paths rely on passing through them. This will hopefully give insight to which nodes are more likely to have a higher transmission rate as betweenness could be related to common layover countries in our graph depicting the flights across the nations.

Methodology

To investigate the effects borders and airlines have had on the Covid-19 pandemic within the EU, we will be creating networks using Python's NetworkX version 2.6.3. The graphs were made on MAC OS. It's important to note that the nodes within the graphs are coloured depending on if they are part of the European Union, with blue nodes being a part of the union and red nodes not. Some graphs also colour the nodes as groups depending on their properties, such as the airports belonging to the same country. The raw data, code and data files are all included in the submission. Each program will produce similar graphs, but they each have a specific attribute they are displaying with it. For instance, one program will produce the clustering coefficients of each node, one will alter the node's size based on its population density, and another will display the normalized betweenness of each country.

Results

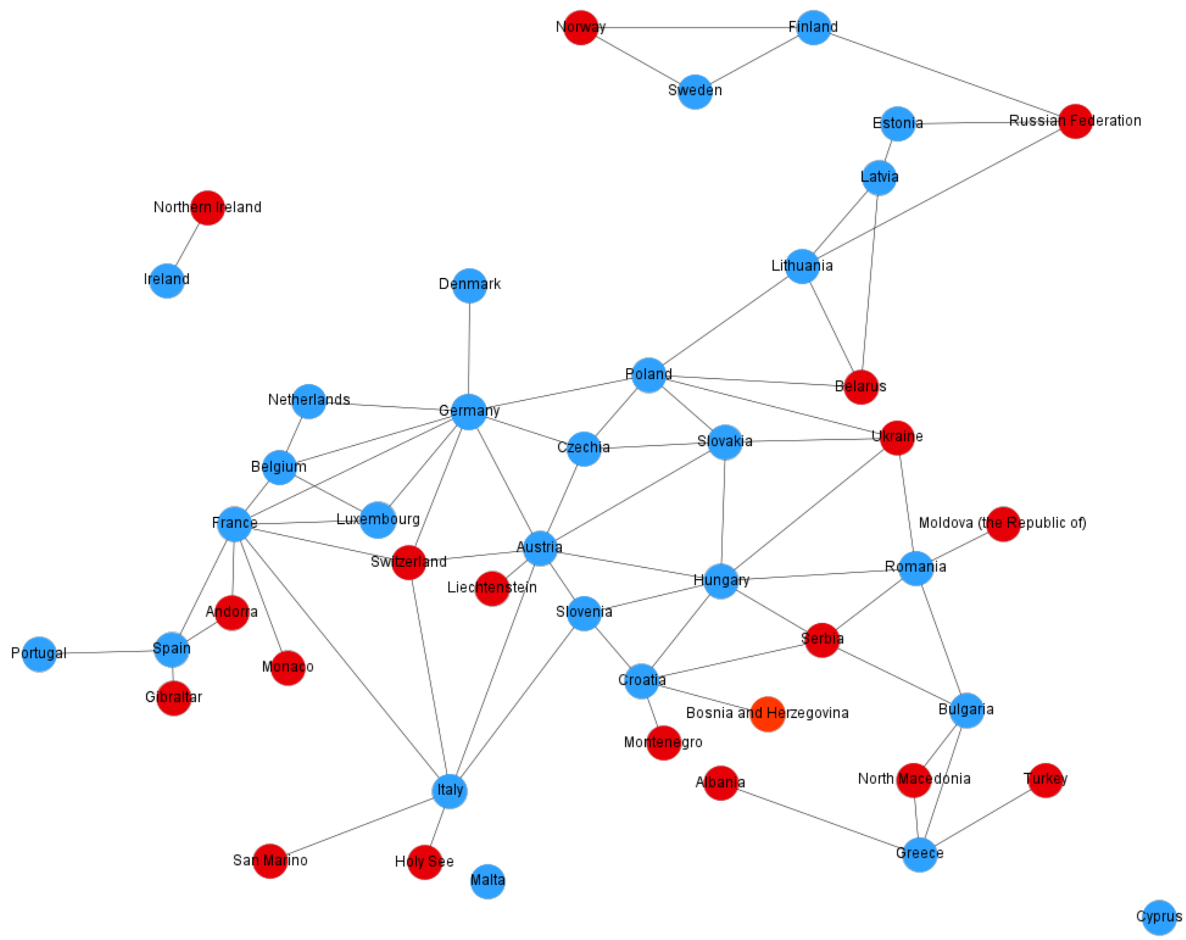


Figure 1: European Countries and Borders

Figure 1 is a basic network graph that depicts nations within Europe. They have been coloured to show which nodes are part of the European Union. The blue nodes are part of the EU, and the red nodes are nations that are not in the EU but are close neighbouring countries. Each edge represents a shared border and all nodes are placed in geographically accurate locations for each country. This graph easily shows us which countries have the most degrees which may influence their importance to our study, such as Germany, France, and Hungary.

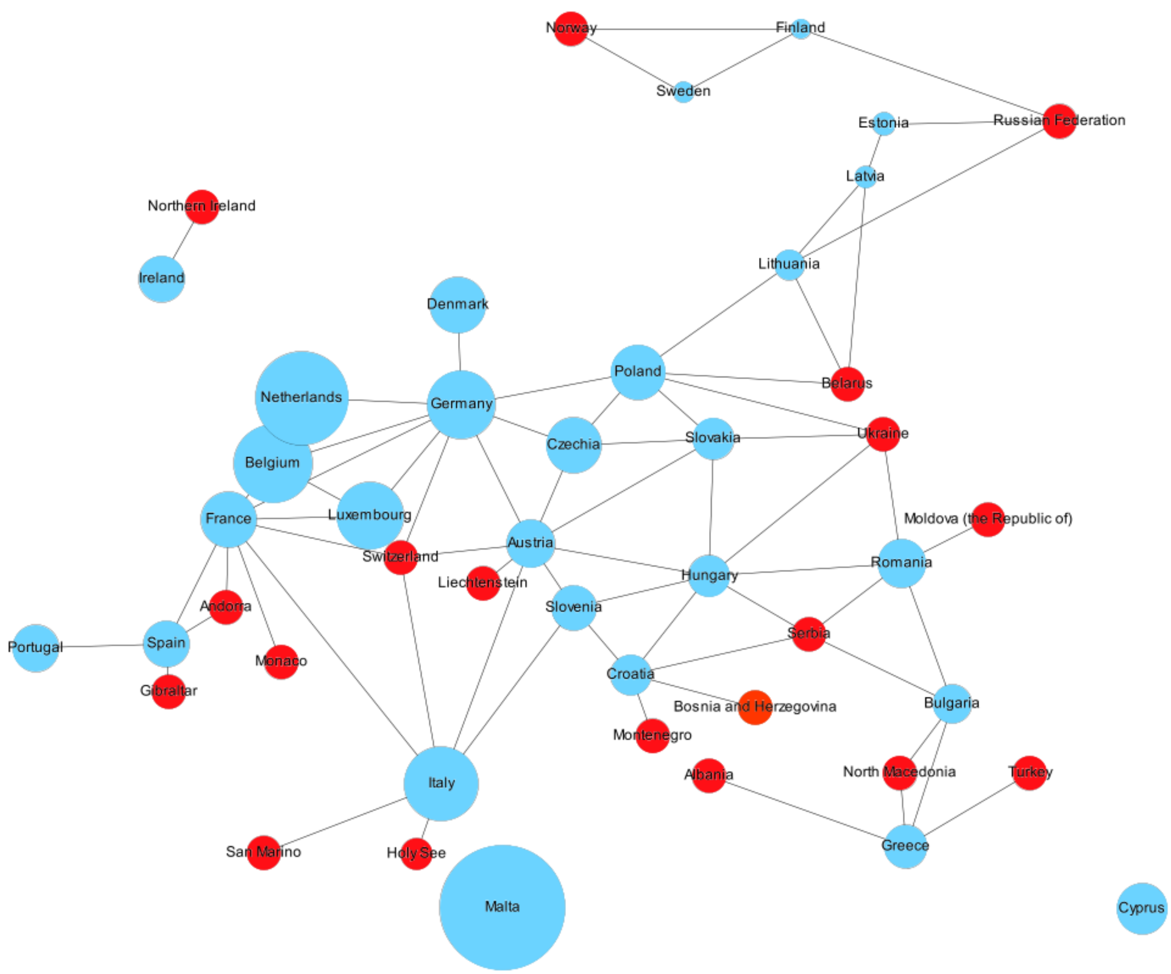


Figure 2: EU border and population density

Figure 2 depicts the population density of each member state, which must be considered when looking at the spread of a contagious virus such as COVID-19. The edges represent borders and the nodes represent countries, with a bigger node representing higher population density. We can see that the highest density populations are Malta, Netherlands, and Belgium. We also see that the smallest density populations are Sweden and Finland. Take note that the red nodes (countries who are not part of the EU) are all the same size as their population density was not tracked. They remain part of the graph for structural balance.

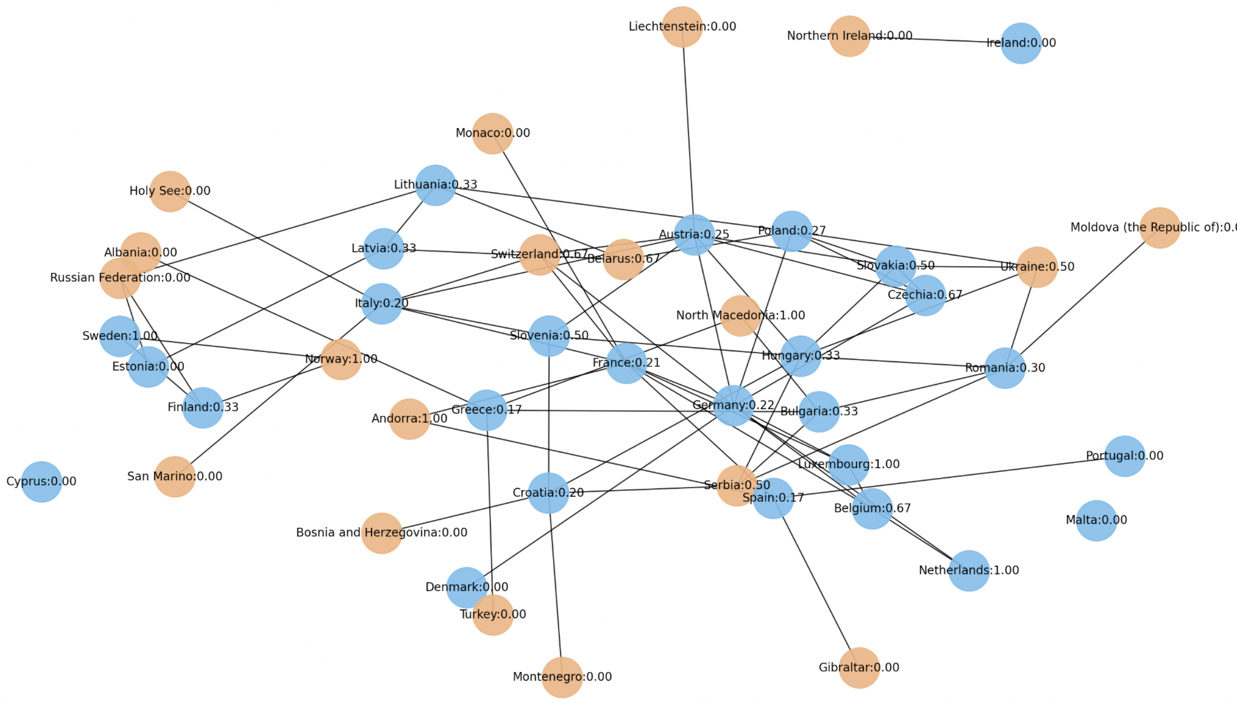


Figure 3: Clustering Coefficient of EU Borders

Figure 3 shows the clustering coefficient of each EU member state using their borders. We can see that nations that share the same clustering coefficient value are clustered together. For example, Luxembourg, Netherlands, Sweden, Norway and Andorra all share a clustering coefficient of 1. Also, countries such as Switzerland, Belgium, Belarus, and Czechia share a clustering coefficient of 0.66. In this case, the clustering coefficient could potentially represent countries that are high risk of spreading COVID-19 due to them closely neighboring multiple member states.

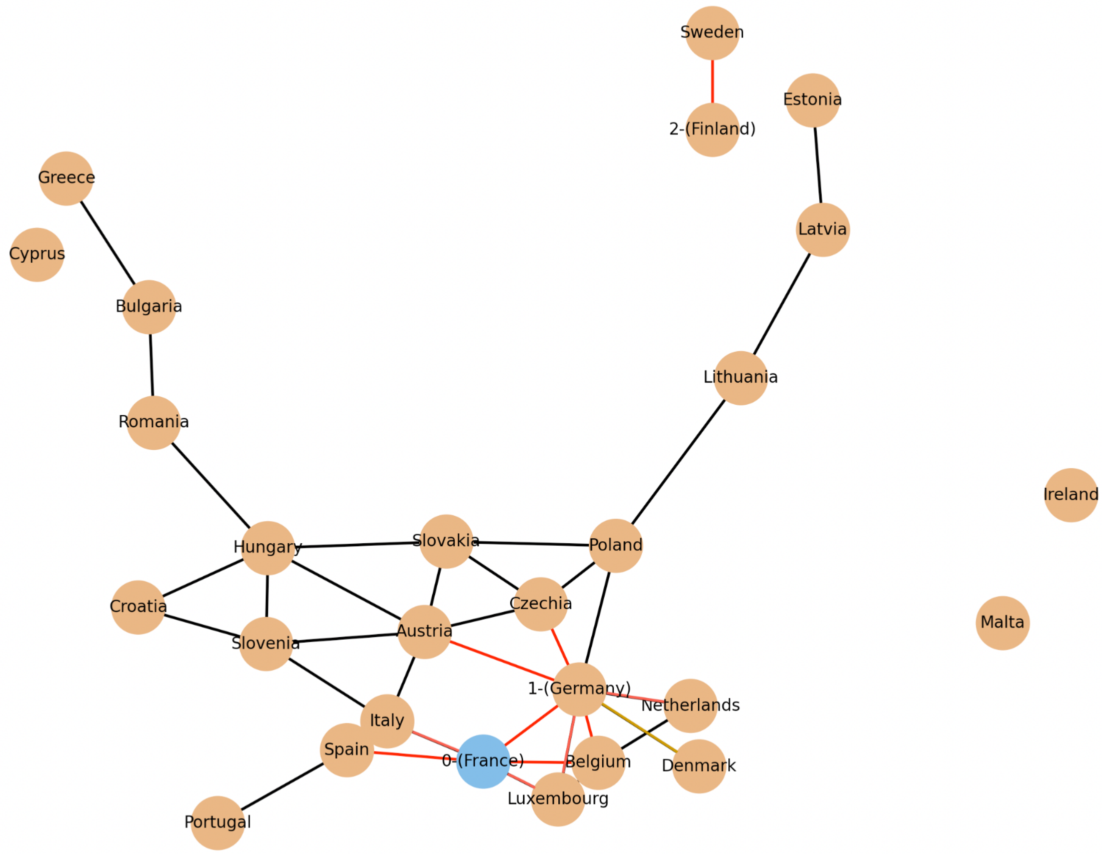


Figure 4: Patient Zero within the border EU network

Figure 4 shows the patient zero within the EU border network. We know France was the first nation to declare cases of COVID-19. Knowing this, we should expect to see a cascade of cases starting from France to the neighboring nations of Germany, Spain, Italy, Luxembourg, and Belgium. We also know Germany was the second country to report cases of COVID-19 [13] so the graph depicts a further possible cascade from Germany.

By tracing COVID-19, we hoped to prove that the virus will cascade affecting one of its closest neighbors first, and then affect a country that it has a triadic closure with. For example the red edges represent a “dangerous” connection. We see that Germany contracted it second. We quickly jumped to the conclusion that because France and Germany have a triadic closure with either Belgium and Luxembourg, this would cause Covid to spread in that region first because networks work to obtain balance within a structure. Surprisingly, Finland was the third to announce a case of covid resulting in our hypothesis, that land borders is the main contributor to covid spread, being wrong.

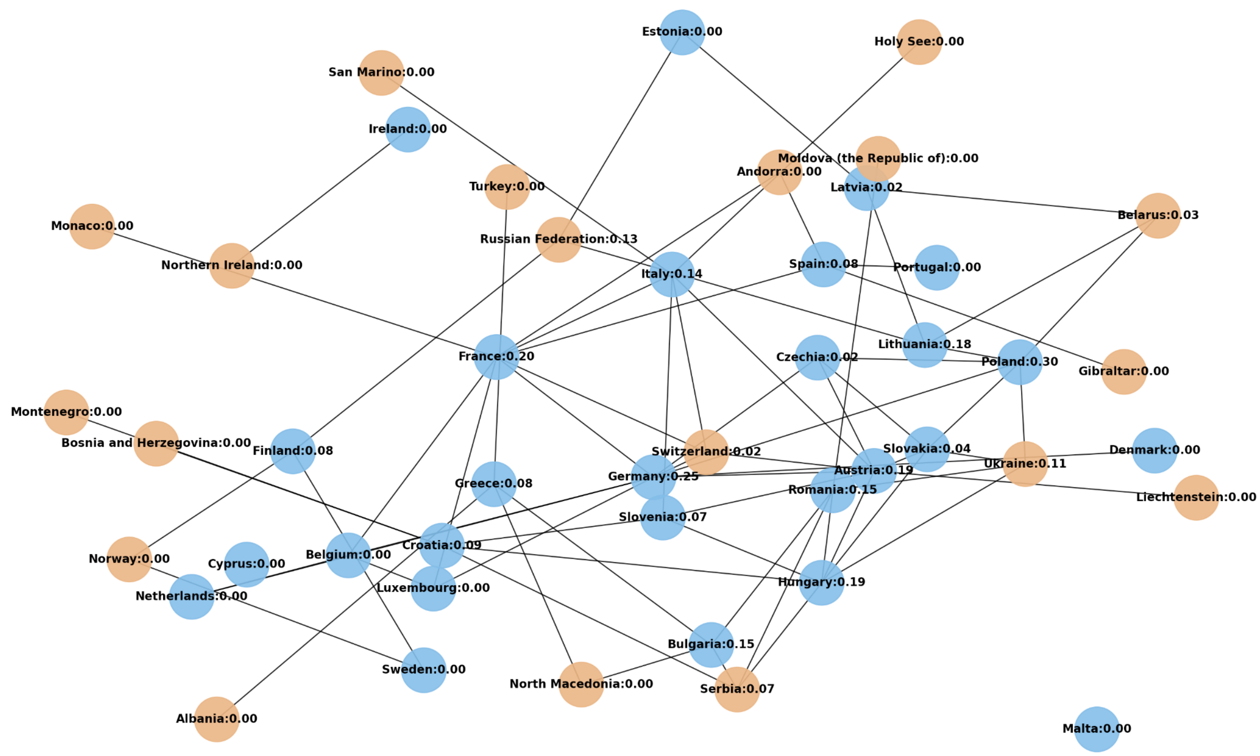


Figure 5: Betweenness of countries and borders within the EU

Figure 5 represents the betweenness of the bordering countries within the European Union. The country that has the highest betweenness is Poland with a normalized betweenness of 0.30. Second, is Germany with a betweenness of 0.25. Third is France with a betweenness value of 0.19. Hungary, Lithuania, Romania and Bulgaria are also all closely tied. Many countries such as Estonia, Netherlands, Belgium, and Sweden show a betweenness of zero.

This data tells us that the borders of Poland, Germany, and France have the highest chance of being crossed over in an attempt to reach another nation via the shortest path possible. When creating our hypothesis about how betweenness would affect the numbers, we assumed that the countries with a higher betweenness would have higher infection rates due to them being key nodes/countries.

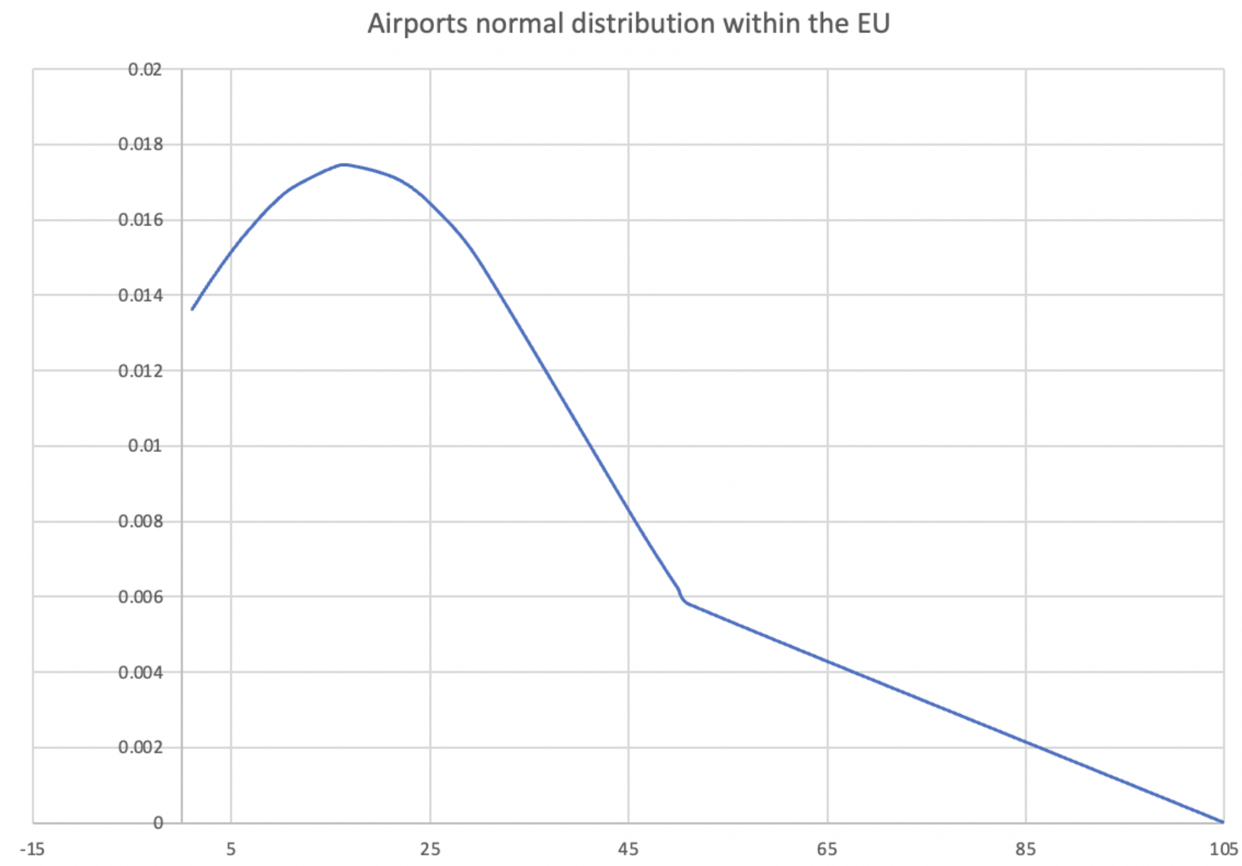


Figure 6: Airports normal distribution within the EU

Figure 6 depicts the normal distribution of airports which is rightly skewed. This indicates that there is a huge difference in the number of airports, with the majority of member states having less airports. This distribution could be proof that countries on the higher end of the distribution such as France contract COVID-19 first.

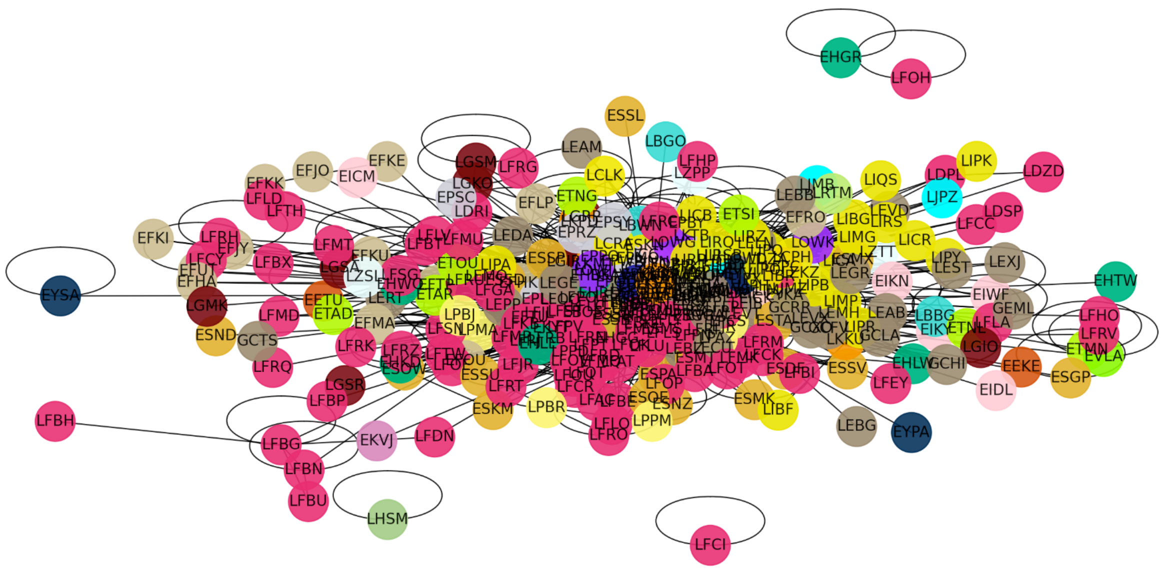


Figure 7: A spring graph for all flights within the EU pre COVID-19 (2019, December)

Figure 7 is a visual representation of all flights that took place within the EU before the COVID restrictions. The nodes are coloured to represent the various airports and the country they belong to. Please view the file GeneratedFlightData/graphLegend.csv for more information about which airport belongs to which country.

Interestingly, we recognized that the flights and airports are representing a bow tie structure. Meaning that some airports had no visitors during the month of December (the out nodes), and others had no incoming flights (the in nodes.)

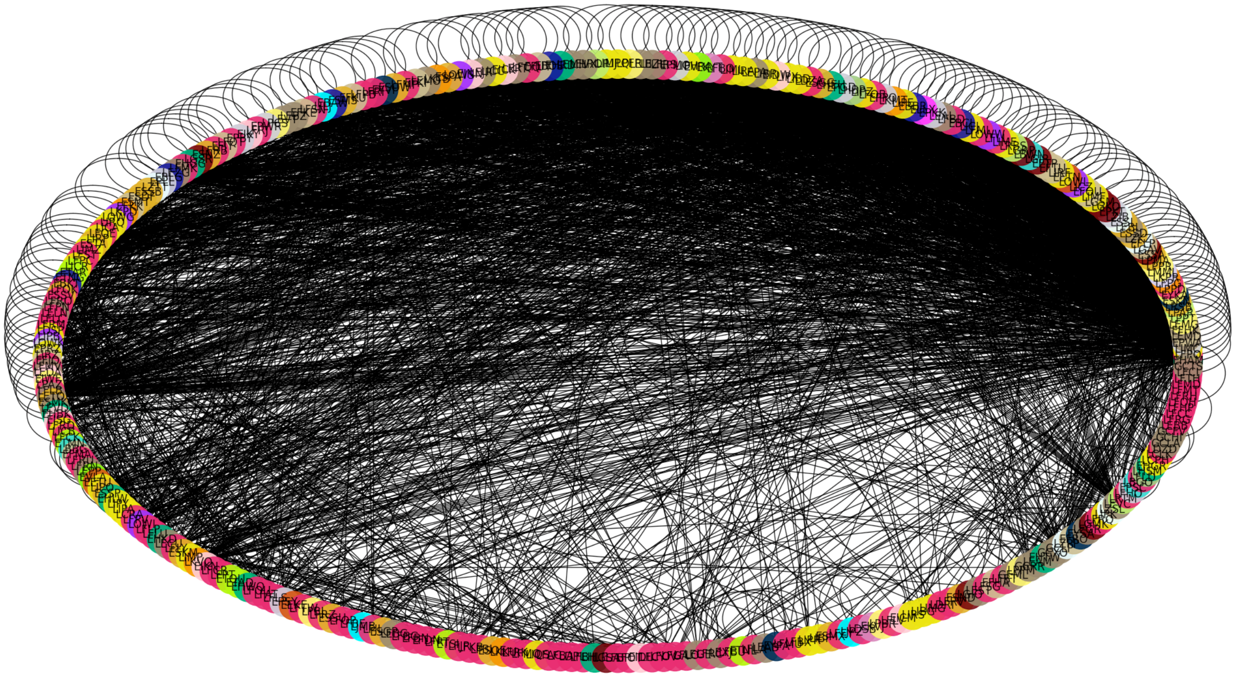


Figure 8: A cycle graph for all flights within the EU pre COVID-19 (2019, December)

Figure 8 was studied to better understand airplane travel within the EU. We found that you can travel anywhere from all 306 airports in the EU by taking at most 6 flights. Thus, our cycle graph of EU flights pre COVID-19 has a diameter of 6.

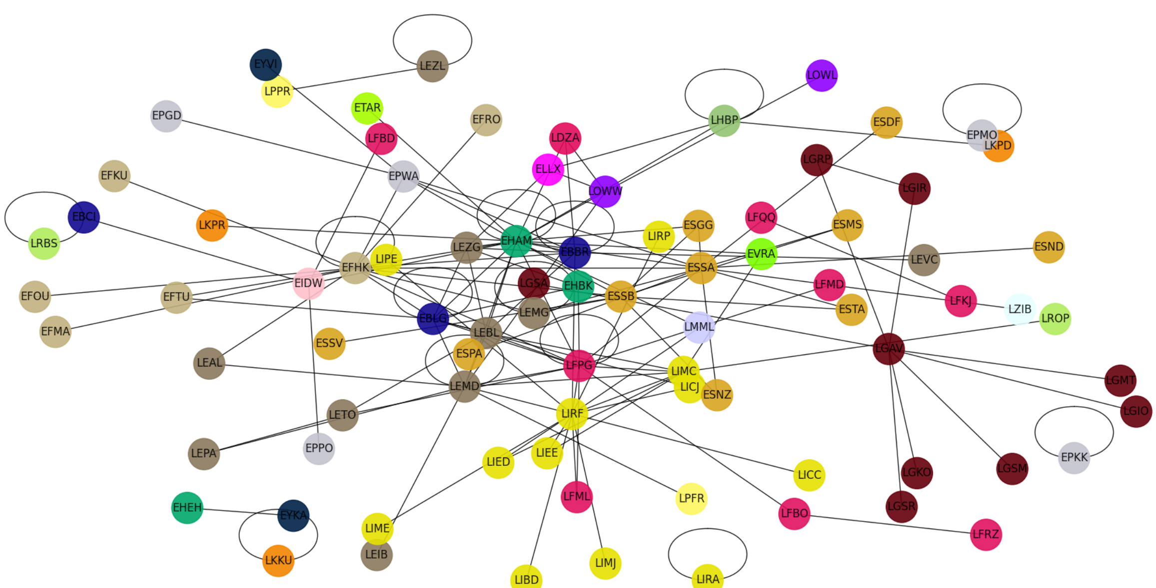


Figure 9: A spring graph for all domestic flights within the EU post pandemic (2020, April)

Similar to Figure 7, the spring graph of the EU also represented a bow tie structure. It seemed that the airports that are located in the center are ones with higher node distribution, leading us to believe that these airports are main contributors to transmitting COVID-19

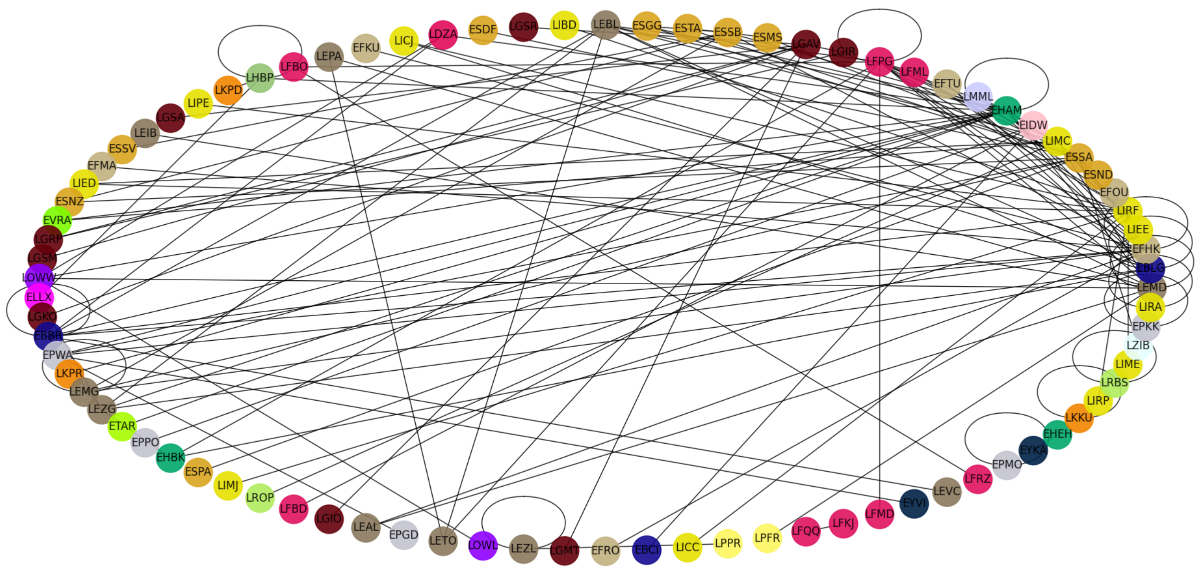


Figure 10: A cycle graph for all domestic flights within the EU post pandemic (2020, April)

Similar to figure 8, we studied the circular graph of the domestic flights within the EU. We were intrigued to learn that although our number of chords decreased by a factor of 14% our diameter also decreased by 1, resulting in this graph having a diameter of 5.

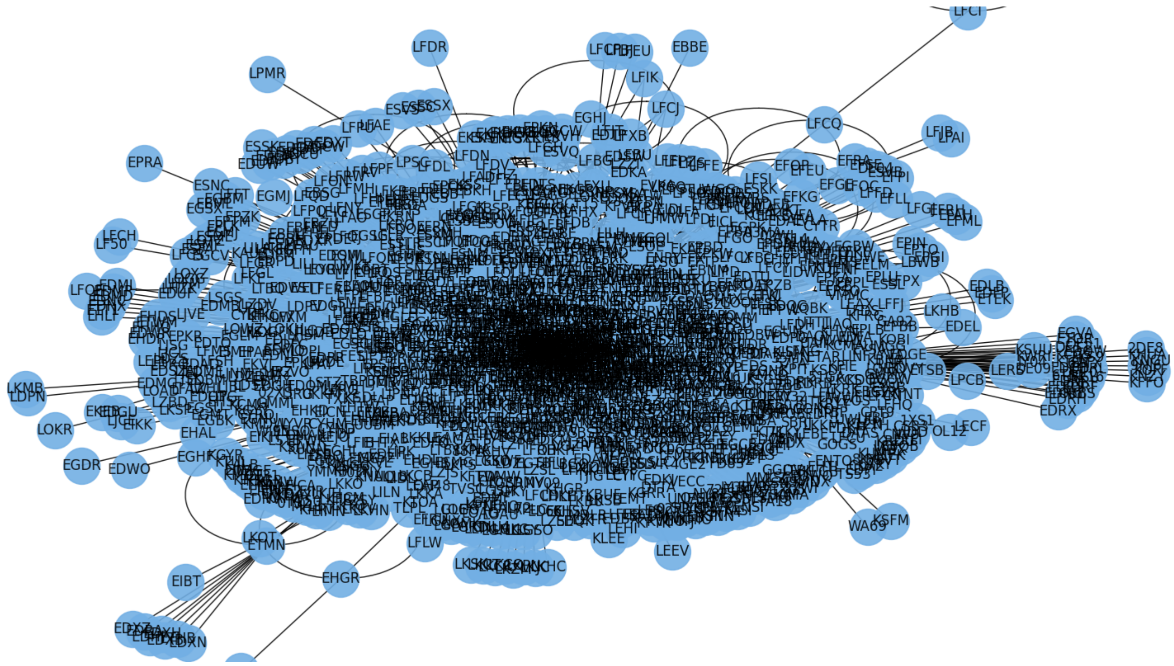


Figure 11: A world wide Spring graph representation of all flights that took place from or to an EU country pre COVID-19 (December,2019)

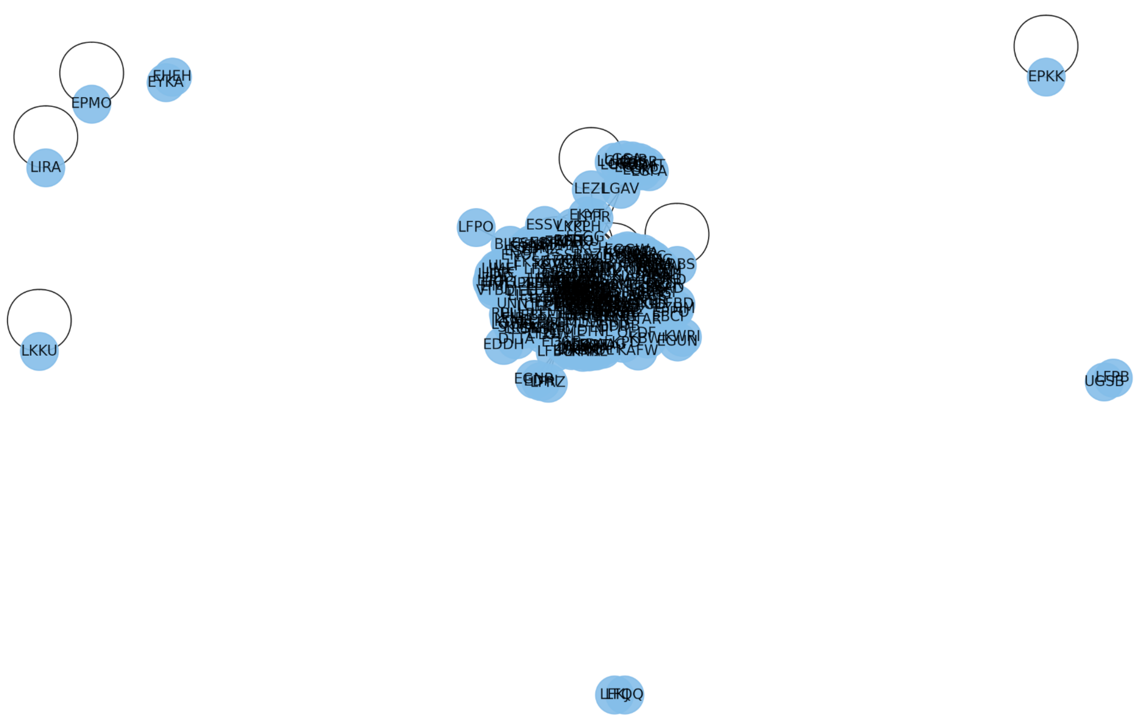


Figure 11.1: The world wide Spring graph representation of all flights that took place from or to an EU country post the state of emergency (April,2020)

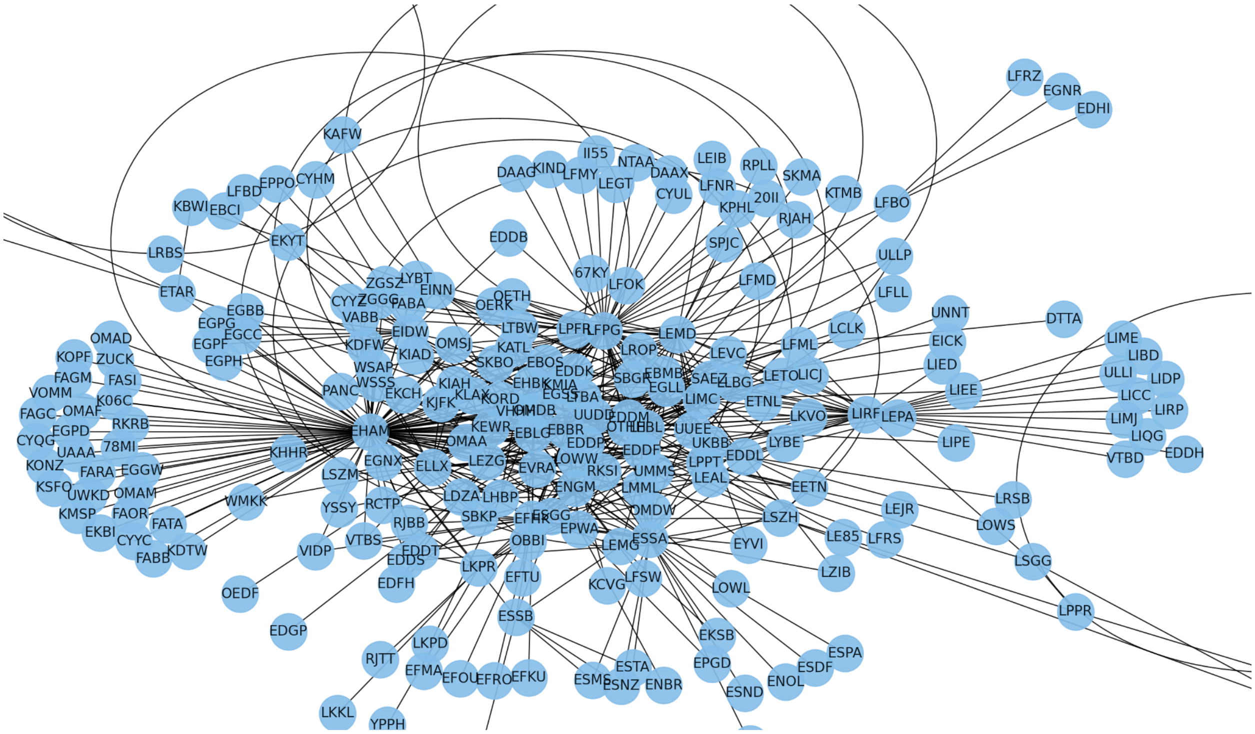
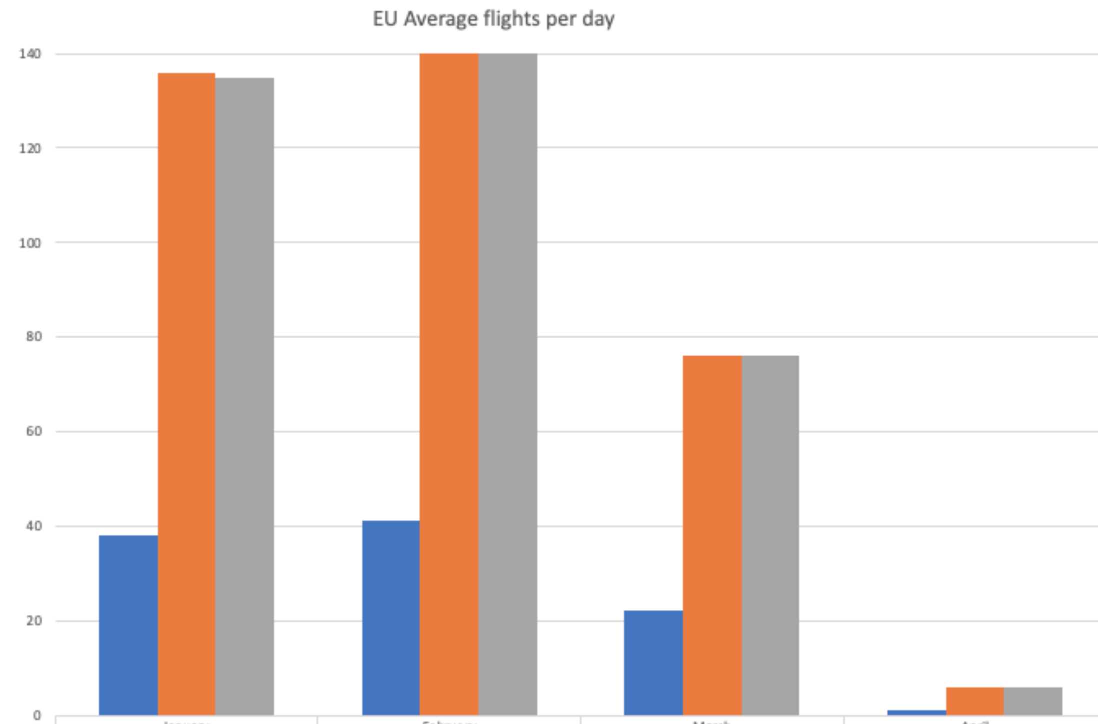


Figure 11.2: A zoom up of the cluster of nodes in the middle of graph 11

Similar to figure 9 and 7, we can see in a closeup of the graph of international flights from/to the eu also represented as a bow tie structure.



	January	February	March	April
Domestic Flights	38	41	22	1
International Arrival	136	144	76	6
International Departure	135	144	76	6

Figure 12:The average number of flights taken per day over the first four months of COVID

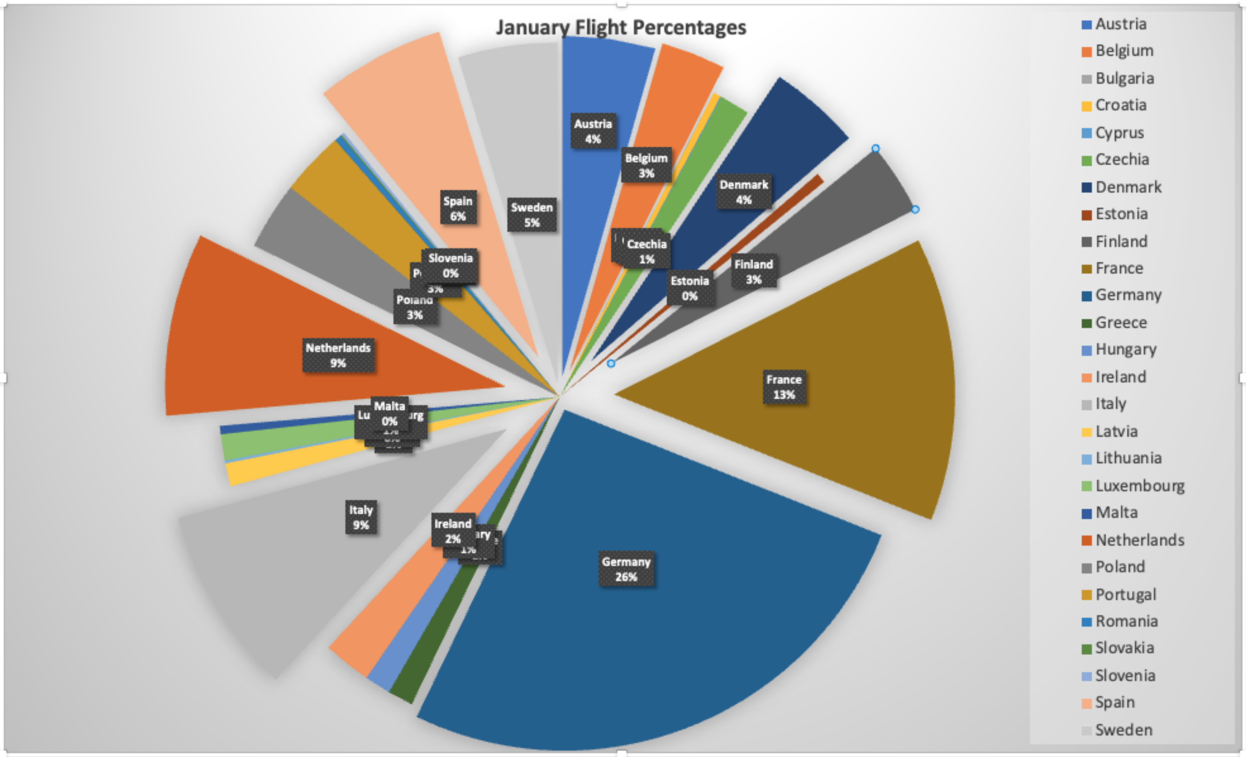


Figure 13:The percentages of air traffic of every country in the EU in the month of January of 2020

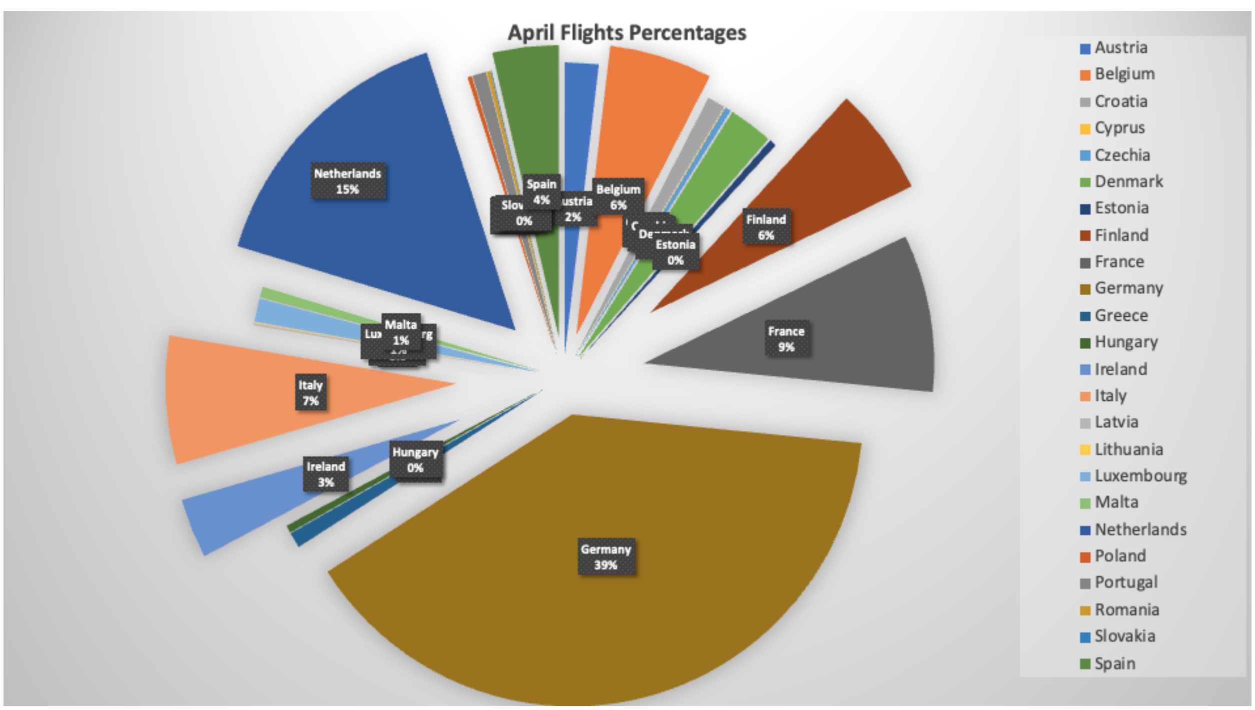


Figure 14:The percentages of air traffic of every country in EU in the month of April of 2020

Country	Airport Code	Betweenness
France	LFPB	0.093
Finland	EFHK	0.061
Czechia	LKPR	0.05
Spain	LEMD	0.048
Netherlands	EHAM	0.044
Greece	LGAV	0.04
Sweden	ESSA	0.037

Figure 15: Airports with largest Betweenness (2019)

location	date	total_cases	new_cases	population	Population/1000	Cases per 1000ppl
Austria	4/1/2020	10711	531	9043072	9043.072	1.184442632
Belgium	4/1/2020	13964	1189	11632334	11632.334	1.200446961
Bulgaria	4/1/2020	422	23	6896655	6896.655	0.06118908369
Croatia	4/1/2020	963	96	4081657	4081.657	0.2359335927
Cyprus	4/1/2020	262	32	896005	896.005	0.2924090825
Czechia	4/1/2020	3508	200	10724553	10724.553	0.3270998801
Denmark	4/1/2020	3107	247	5813302	5813.302	0.5344638899
Estonia	4/1/2020	779	34	1325188	1325.188	0.5878411214
Finland	4/1/2020	1797	125	5548361	5548.361	0.3238794303
France	4/1/2020	57072	4843	67422000	67422	0.8464892765
Germany	4/1/2020	77872	6064	83900471	83900.471	0.9281473521
Greece	4/1/2020	1156	0	10370747	10370.747	0.1114673803
Hungary	4/1/2020	525	33	9634162	9634.162	0.05449358232
Ireland	4/1/2020	3447	212	4982904	4982.904	0.6917652839
Italy	4/1/2020	110574	4782	60367471	60367.471	1.831681834
Latvia	4/1/2020	446	48	1866934	1866.934	0.2388943583
Lithuania	4/1/2020	512	44	2689862	2689.862	0.1903443374
Luxembourg	4/1/2020	2319	141	634814	634.814	3.653038528
Malta	4/1/2020	188	19	516100	516.1	0.3642704902
Netherlands	4/1/2020	14713	1093	17173094	17173.094	0.8567471884
Poland	4/1/2020	2554	243	37797000	37797	0.06757150038
Portugal	4/1/2020	8251	808	10167923	10167.923	0.8114734937
Romania	4/1/2020	2460	215	19127772	19127.772	0.1286088103
Slovakia	4/1/2020	400	37	5449270	5449.27	0.07340432755
Slovenia	4/1/2020	841	39	2078723	2078.723	0.404575309
Spain	4/1/2020	104118	8195	46745211	46745.211	2.227351161
Sweden	4/1/2020	5320	486	10160159	10160.159	0.5236138529

Figure 16: Pandemic Data for European Union Countries for April 1, 2020

Discussion

With Figure 7, we are able to see all airports and flights within the EU. This graph resembles a bow-tie structure of the web [17]. On the left, there are many nodes with edges going towards the center, where there is a large cluster of nodes which we can consider a strongly connected component. This large cluster of nodes has connections to the out nodes on the right. There are also some disconnected components and tendrils that do not feed into the largely connected component center. This bowtie resemblance tells us that there is a lot of traffic within the center and will be a large hub for transmissions.

Figure 4 displayed the beginning of the pandemic in Europe, with France being the first country to report a case of COVID-19. A triadic closure starting from France includes Belgium and Germany. Interestingly, Germany was also the second European nation to report a case of the virus, not long after Belgium reported one as well. With these countries forming a triadic closure, it is possible that the cases in Belgium began from being connected to two positive nations.

Changes are bound to occur as time passes. With only five months between Figures 7, 8 and 9, 10, drastic changes can be seen. This shows that the networks evolved over time and the changes in air travel frequency changed and in doing so, the graph lost a large number of nodes and edges. This scenario exemplifies growing, or in this case, shrinking, networks.

We previously hypothesized that flights with the highest betweenness would see the largest influx of cases as the pandemic broke out. The highest betweenness value before the airline pandemic measures came into place belonged to France's LFPB airport (Figure 15) and France was also the first country to report cases within the EU. Although we can’t be sure if the betweenness contributed to France being the first country to catch COVID-19 since the infecting flights arrived outside the EU, we can formulate that flights that transit through this airport are high risk given what we know about how COVID-19 spreads.

In the data collected for April 1, 2020 as shown in Figure 16, we were able to sort out the case rates per 1000 people per country. In the results, we are shown the countries in the EU with the highest rates of COVID-19. The top five are Luxembourg (3.6 per 1000), Spain (2.2 per 1000), Italy (1.83 per 1000), Belgium (1.2 per 1000), and Austria (1.18 per 1000). This goes against our initial hypothesis of countries with the most degrees and highest betweenness having the most cases. Luxembourg has a degree of three, is the second least populated nation in the EU, a betweenness of approximately zero, and has only one major airport. Based on our hypothesis, we believed that a country like Germany would have the highest rate as it has the second highest betweenness, a degree of eight (not including not EU countries), and approximately seventy medium and large scale commercial airports, and the highest number of flights, with 28% to 39% of all air traffic from January to April of 2020 (Figure 13 & 14).

However, Luxembourg does have a higher clustering coefficient than Germany, which could imply that clustering coefficients are a better indicator of transmission rates being higher.

Limitations

Our results have inherent limitations. For example, the data may not be entirely accurate. Time has proven that there are often false test reports (such as false positives) that will cause incorrect numbers to be worked with. Countering that point, there is also a large number of people who were infected that were not tested, again altering the numbers. When looking at COVID-19 over a network, many factors play into case transmission that were not accounted for. Additional limitations include not knowing the amount of passengers on the flights, any spread of the infection within the airports or flights, and the impact of incoming flights from countries outside of the EU has on the transmission numbers. We did not look at other modes of transportation such as ships or railways as well. A final limitation we faced is that our data from Opensky had incomplete flights, resulting in us completely disregarding the data.

Conclusion

Extensions to our work could involve investigating the impacts of other types of transportation such as railways and general border traffic from crossing vehicles. This information would further conclude how large of a role border crossing had on spreading COVID-19 internationally into a country rather than it spreading domestically.

Further work could also involve extensive simulations to test how reducing flights would affect the transmission rates of COVID-19. By restricting flights or hypothetically having a country on lockdown, the simulation would exemplify node blocking, where theoretically it should drastically reduce the transmission of the virus of that nation since no one can leave or enter it. This would make the node practically untouchable as well; this may affect other nodes since the lockdown node would have no out degrees to other countries.

COVID-19 which initially started as an epidemic in Wuhan, China has become a pandemic that's affected every nation due to rapid access to international travel. COVID-19 also has an initial estimated R_0 between 1.4 and 2.4 [7], with government's around the world taking extraordinary measures, such as lockdowns and excessive debt, to help contain the spread of the virus. We investigated COVID-19 within the European Union due to its member states' close proximity, free crossing agreements, and numerous airports within each country. Understanding COVID-19's spread between borders and airports around the world, we posed the research question: how do airlines and borders affect transmission of SARS-CoV-2 in the EU? Using NetworkX and data from sources such as Our World In Data and various flight tracking websites we created different network graphs to examine the role borders and airlines played in the spread of COVID-19 within the EU. We hypothesized countries with more airports would have higher rates of COVID-19, with countries with multiple shared borders acting like influential nodes and spreading the virus quickly to its neighbors. We found that a country's betweenness and clustering coefficient value did not have a connection to their rate of COVID-19. Therefore, our hypothesis was wrong, we found borders and air travel have little to no effect on the rate of transmission; however, this may be due to our limitations when studying the COVID-19 networks within the EU.

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