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Role of urban planning characteristics in forming pandemic resilient cities – Case study of Covid-19 impacts on European cities within England, Germany and Italy

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ABSTRACT

In recent decades, the world has witnessed a variety of emerging infectious diseases, some of which developed to pandemic world threatening outbreaks, the ongoing COVID-19 is known to be taking the lead in claiming lives around the globe and thus, urging people to trail its increasing figures. Therefore, this research aims to emphasize the role of urban planning in containing such outbreaks through running a series of analytical and statistical studies on European cities, worst inflicted region, to analyze the main urban features they share and that may be propagating the disease spread according to their population size, density, form, intracity connectivity and intercity connectivity. This study, as far as we know of, is the first practice to evaluate both the individual and combined impacts of these factors on recorded rates of infections. According to the context of this research, it is concluded that the diversity found in urban features are, to a large degree, related to cities being more vulnerable than others. Intracity connectivity through public transport is found to be the possible prime factor of this study, and is followed by population size, density, and intercity connectivity. Urban morphology seems to also contribute to such outbreak, with both radial and grid cities being associated to higher infections rates as to linear cities. Henceforth, setting priorities in post-pandemic urban planning schemes is essential for planning resilient cities that are capable to thrive and maintain functionality with lowest possible infections amid else possible diseases that are to follow in severity.

1. Introduction

Many previous international studies and research papers handled issues regarding the individual impact of a certain urban feature on disease spread within cities and have had significant contributions to the body of urban planning. Some of which are closely relevant with the research's targeted features and have had conflicting outcomes, as some studies claimed specific urban features to having effective impacts on the pandemic spread, while others have not, i.e.; (Tian et al., 2020) regarding intracity connectivity (Chinazzi et al., 2020) and (Zhang, Zhang, & Wang, 2020) regarding intercity connectivity, (Stier, Berman, & Bettencourt, 2020) and (Jahangiri, Jahangiri, & Najafgholipour, 2020) regarding city population size, (Carozzi, Provenzano, & Roth, 2020) and (Tian et al., 2020) regarding city density. This study however observes and analyzes the impact of several urban morphological

features, regarding all their population size, density, intra-city connectivity (modal share), inter-city connectivity (regional-international connectivity), and city form (urban morphology). This study not only highlights the impact of each of the mentioned urban features, but also how they combinedly affect the spread of COVID-19. Therefore, this research is a method to investigate for mutual urban characteristics within European cities that are known to be the worst affected regarding their condition of infection spread. For the study assumes that there is a strong correlation between COVID-19 infection rates and a city's urban characteristics. Nonetheless, many other factors also contribute to the spread of COVID-19, and that solely linking disease transmission to urban planning features is considered unlogic. Socioeconomic factors for instance are of inevitable importance, but due to the limitations of this paper regarding city-level data collection for such factor is inaccessible for all 27 sample cities and mainly available on national levels only.

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However, socioeconomic dimensions are also reflected to some extent through study-handled factors as population density, Modal share values, and regional-international connectivity of cities. Since higher population density tend to decrease the natural endowment per capita as opposed to lower densely populated cities. As for cities that rely on proper public transportation infrastructure and are internationally connected reflects a good economic foundation.

2. Literature review

There are many ways that city planning, and urban design can alleviate, or aggravate, the spread of public health risks. Long before data statistics were accessible, health officials suspected city amenities, layouts, population size, and sanitation measures were in some way related to how diseases spread that in turn led to fierce complications of epidemics (Matthews, 2018). The 21st Century has so far witnessed a variety of different nature like diseases, either viral or bacterial, such as SARS, MERS, Ebola, bird flu, swine flu and the ongoing COVID-19. And since the world is recently considered a gateway welcoming new pandemics, new methods of city designs are in desperate need to prevent outdoors in becoming prohibited zones, instead, remaining a safe and habitable space (Constable, 2020). Therefore, The COVID-19 pandemic is an opportunity to target focus on what can and should be changed, to re-evaluate the way cities are built, maintained, and lived in (Ellis, 2020).

Moreover, sets of serious issues came forward amidst the COVID-19 pandemic strike, and while the impacts are yet to be holistically understood, it seems obvious that this crisis will visually injure cities, both physically and socially, and will echo for generations (Berg, 2020). some of which include fear and confusion, risks of illness and deaths, healthcare system stress and insufficiency, travel restrictions, isolation and quarantine requirements, mental and physical stresses, plus income loss to individuals, businesses, and governments, which in turn threatens local, national, and global economies (Litman, 2020). Henceforth, cities and towns preparedness levels towards pandemic attacks are prompter than ever in the sake of disaster risk reduction (UN-HABITAT, 2020). Therefore, This pandemic era is a call for all urban planners to embody health aspects fully to their planning schemes, both in policy and practical terms, "For the resilient, sustainable cities we all want and need, urban plans need to be designed, evaluated and approved using a health lens, (Brennan, 2020)" says Layla McCay, director of the Centre for Urban Design and Mental Health.

Urban resilience thus, plays a significant role in pandemic disaster city planning, as it refers to the ability of any urban system to maintain continuity through all shocks and stresses while positively adapting and transforming towards sustainability (UN HABITAT: Resilience). In addition, enabling cities to assess, prepare for, and respond to all hazards of different natures, expected or unexpected, sudden or slow-onsets, and can therefore protect and enhance people's lives (El-Gazzar, 2019). Accordingly, and in the light of COVID-19, it is essential to conclude that resilience in city planning branches further beyond climate, landscapes, ecology, and natural disasters (Cheng, 2020). Instead, bolstering the ability of urban environments to absorb such a blow without a meaningful change in structure or function (Lak, Asl, & Maher, 2020). Therefore, it is essential to closely perceive any existence of relation between urban planning and disease spread, in order to implement a resilient city planning scheme that empowers post pandemic cities to combat future attacks. This means that cities can become resilient only if they shift their attention from simply bouncing back to where they were before, to bouncing forward to a better place (Davoudi, 2020). Hence, many questions are driven from the strike of COVID-19 pandemic, some of which are: Was it a "Bad City Planning" that made "the Coronavirus crisis worse?", "Is density and clustering, make residents more vulnerable to diseases, terrorist attacks, crimes and traffic accidents and natural disasters?" (Danesphour, 2020). There is apparent evidence, that will be further illustrated, that urban form and design factors can greatly

influence the dynamics of pandemics in respect to their densities, connectivity, size, and form.

In trying to study and analyze the various aspects and characteristics behind the aggravation of this outbreak, many inspecting the spread trend of this novel virus rushed to blame density (Florida, 2020), making it one of the most controversial and influencing factors that stood out puzzling many and delivered questions as to whether urban density and healthy cities are closely related. After all, physical distancing has been the most common measure to contain the spread of the virus. Nonetheless, this does not mean higher-density cities are necessarily more vulnerable and lower-density cities more resilient to the pandemic (Pafka, 2020). In theory, dense communities do lead to more social interaction among residents, equipping them in becoming potential epicenters due to the rapid spread of pandemics. However, on the other hand, dense areas may be better environments in taming and forcing strict measures and policies as social distancing, in addition to having better access to health care facilities (Hamdi, Sabouri, & Ewing, 2020), for cities often need to meet a certain threshold of population density to offer higher-grade facilities and services to their residents. For instance, in dense urban areas where the coverage of high-speed internet and door-to-door delivery services are conveniently available at competitive prices, it is easier for residents to stay at home and avoid unnecessary contact with others (Fang & Wahba, 2020). This too was confirmed by the UN Habitat professionals as they pointed out the vast differences between cities with a well-planned density and overcrowded ones, as well-designed urban density, at a human scale that includes adequate facilities and functions to balance long-term social, economic and environmental sustainability, can enable a level of resilience to the impacts of the pandemic without compromising livability (UN HABITAT, 2021). A study carried out by (Khavarian-Garmsir, Sharifi, & Moradpour, 2021) also confirmed such finding, as it was found that overcrowding is what triggers disease spread which can occur even in low density districts.

Given the fact that cities are designed and planned for intense socio-economic interactions, big proportions of their measurable characteristics - from the size of their economies to their crime rates, to the prevalence of certain infectious diseases - are heavily dependent on the scale of these interactions, that is in turn a reliant factor upon population size (Bettencourt, 2013). As for Eric Huybrechts, regional planner at the Paris Region Institute said that "large cities have been at the epicenter of the crisis, starting with Wuhan. He said as cities continue to grow such pandemics are increasingly inevitable and new planning and design approaches are essential to prevent and adapt to future crises, protect citizens and prepare for upcoming pandemics" (Nairobi, 2020). This is backed up with other findings in Brazilian cities that denoted higher infection rates in larger cities than in small cities, however, lower death rates in larger cities than in smaller cities, this perhaps is linked to the existence of proportionally more health infrastructure in the largest cities and a lower proportion of older adults in large urban areas (Ribeiro, Sunahara, Sutton, Perc, & Hanley, 2020). City size has also been found to be an influential key factor on viral disease spread of the US cities. This may indicate that policymakers need to implement more aggressive protection measures in larger cities (Stier et al., 2020). As for the UN-Habitat organization, they revealed that larger cities were confronted with higher initial growth rate of covid-19 and linked this finding to the fact of their greater connectedness properties, as large metropolitan areas with a higher number of counties cause natural movement of people and thereby greater risks of infections (UN HABITAT, 2021).

International connectivity is another vital factor in disease spread, for pandemics are defined as "an epidemic occurring worldwide, or over a very wide area, crossing international boundaries and usually affecting a large number of people" (Kelly, 2011). Global airline networks thus play a key role in the global importation of emerging infectious diseases (Adiga, Venkatramanan, Peddireddy, & Telionis, 2020). Regarding COVID-19 pandemic, the outbreak had spread to 24 other countries

around the world in a matter of few weeks through international transportation, including the United States, Canada, the United Kingdom, France, Australia, and Japan (Kelly, 2011). Other studies show that the number of daily certified cases of COVID-19 infections is strongly linked with the trips made 21 days before (Carteni, Di Francesco, & Martino, 2020). Consequently, numerous countries have implemented control measures related to international travel that included complete closure of borders, partial travel restrictions (e.g. restrictions on air travel only, or restrictions on travelers from certain countries), entry or exit screening, quarantine of travelers (Burns et al., 2020). However, other studies claimed that suspending means of international transport has proven to be effective only in delaying the spread elsewhere around the globe rather than preventing it, giving countries the time to prepare for its inevitable occurrence. And that suspending international transportation later on through the pandemic is considered ineffective. While another study targeting Chinese cities reveals that travel restrictions were particularly useful in the early stage of the outbreak when it is only confined to a certain area that acts as a major source, as they found that the magnitude of the early epidemic outside of Wuhan, China's epicenter, was very well predicted by the volume of human movement out of Wuhan alone (Kraemer et al., 2020). (Wei et al., 2020) Supports this finding, as a simulation study was carried to reveal the high impact of intercity connectivity on disease transmission when lifting lockdown measures in the early stages of the pandemic strike.

And since viral contagious diseases are transmitted through relatively close contacts between infectious and healthy individuals, crowded centers such as means of public transportation and transportation hubs act as disease addicted zones and hotspots for such crisis diffusion (Goscé & Johansson, 2018). Generally, population movement and transportation infrastructure that increase inter- and intra- urban connectivity, are considered as key factors contributing to the spread of infectious diseases, and their role in previous diseases outbreaks (e.g., Ebola) has already been documented (Connolly, Harris Ali, & Keil, 2020). Accordingly, governments and authorities have been trying to tame this issue by announcing official guidelines that discourage the use of public transportation. The United Kingdom clearly advises, "You should avoid using public transport where possible" and "Consider all other forms of transport before using public transport" (Department for Transport, U. K, 2020). In the United States, it is suggested that employers should "offer employee's incentives to use forms of transportation that minimize close contact with others (e.g., biking, walking, driving, or riding by car either alone or with household members)" (Centers for Disease Control and Prevention, 2021). Therefore, public transport systems around the world have seen ridership and revenue plummet and have been forced to cut off services (United Nations, 2020), thus, contributing, and aggravating issues that in turn impedes the implementation of sustainability attempts that encourages the use of public transport. For not only half of the world's urban population had adequate access to public transportation before the pandemic hit (Secretary-General, 2019-2020), but also the COVID-19 added unprecedented measures changing travel habits in many countries. As many users have started to prefer traveling by private cars, which is against the sustainability policies of the European cities. Their perceptions of using sustainable urban mobility modes have emerged for future transport planning (Campisi et al., 2020). This condition if not halted or reversed, will surely contradict with sustainability goals and policies regarding efforts to tackle climate change and air pollution (United Nations, 2020). Therefore, it is of inevitable importance to trace public transportation dependency rates in cities to broadly understand its correlation with the spread of infectious outbreaks, and whether or not makes cities more vulnerable than others during such crisis.

This research is an attempt to comprehend why developed countries are the worst hit regions despite their awareness and preparation they are persistent on having and were constantly pursuing for. In addition, why different cities showed incredibly higher infection rates than others

regardless of their health care systems and the strict measures applied upon them, while others only experienced slight interruption in daily life habits despite being located within the same geographic boundaries of the same country. Therefore, this research aims to analyze their main urban features, relevant to the discussed above urban factors that mediate disease spread, according to their rates of infections to fully clarify any existing relations for future implementation in post pandemic city planning schemes.

3. Methodology

Since cities vary significantly by their infection rate during a pandemic crisis, it is important to track infested cities by their urban characteristics, as it may propagate or limit disease spread (Florida, 2020). In order to do so, this research pursues a combination of both qualitative and quantitative methods, through presenting and concluding previous and contemporary literature studies, to analysing collected data. Thus, this study utilizes the compiled data method to collect data from different official and reliable sources in order to have them processed through a set of statistical tests. These approaches are all used to address the main aim of this research in determining whether urban characteristics of cities have an influential impact on the spread of pandemics in general and for the present COVID-19 crisis. This study also took the opportunity to observe these findings during the ease and lift of strict lockdown measures, around the period of mid-June to late July, to efficiently assess functioning cities from others. Therefore, this research focused its study on European cities within England, Germany, and Italy, for being the countries that are the most affected among others. And to eliminate potential confounding variables and errors, the study followed a sampling procedure by targeting three of the highest and lowest infested cities along with three other cities located in the middle of the spectrum of each country. To determine the main features and characteristics that form each city individually, each city was analyzed in respect to their population size, population density in built up areas, urban form whether it is a compact, dispersed, radial or linear shaped cities. In addition to examining the main characteristics of each city, urban connectivity is another major factor that greatly influences the density and movement of people, thus the spread of diseases. Therefore, this study highlighted the importance of retrieving the Modal share/split value, which is a percentage rate of public transportation dependency, for public transportation is an effective element affecting urban connectivity, the higher the Modal share value, the more connected a city is, thus, the bigger the flows of movements are. In addition to Modal share values that assess local connectivity levels of cities, the regional and international connectivity status of cities are also vital data that need to be obtained and linked to rates of infections.

After successfully retrieving all previously mentioned data, graphical and statistical analysis then follows, giving a detailed comparison of all 27 cities, along with an evaluation of the combined effects of city studied features on disease spread. This study accordingly employs the following tests: Pearson correlation, Spearman correlation, ANOVA test, Regression analysis; multicollinearity, autocorrelation, that to highlight the key outcomes of this research and conclude effective recommendations in planning for a pandemic resilient city in post pandemic world.

4. Data collection

This research depended on secondary data as a method for data collection and followed a set of criteria for the sampling procedure of cities. The city size factor is measured by the means of its population size rather than its geographical area since viral diseases are known to be transmitted through people's interactions. Cities were therefore selected to meet the standard size of an urban city no less than 100,000 inhabitants. City density data however addressed the urban density of population occupancy within an urban land area. As for modal share values, others may refer to as modal split, were retrieved according to

the percentage of people depending on public transportation (PT) (i.e.: buses, trams, ..., etc.), mass transit systems, as their primary means of transport to assess how reliant cities are on this specific form of transportation. Regarding the city regional and international connectivity levels, the data collected considers the diverse modes of transport within each city, in addition to their scale of service (i.e.: Regional/international) that will be further illustrated. City forms are acknowledged by the morphological pattern of growth observed in its urban fabric and is categorized into either radial, linear or grid shaped patterns. And since all cities were analyzed based on their pandemic levels and given the fact that this study was conducted through a specific period, around early June to late July, the disease transmission was thus measured by its rate of spread rather than by its total number of cases. For in epidemiology, a rate is a measure of the frequency with which an event occurs in a defined population over a specified period of time (CDC, 2012). And by following the sampling method mentioned above regarding population size, the infection rate is consequently measured by the number of incidents per 100,000 people. Table 1 provides all data related to the discussed above study factors.

4.1. Intra-city connectivity (modal share)

During pandemic strikes, it is important to fully understand the norm of disease spread caused by the movement of people. Therefore, the more connected a city urban fabric is through public transportation, the more accessible it becomes, the greater the flows of people are accordingly. In order to assess this in practical terms, this study carried out a graphical analysis showing the influence of public transportation (PT) modal share values on the rates of infection, as seen in Fig. 1.

From previous figure, the existence of a positive strong correlation between modal share values and infection rate listings of European cities is evident, with over 80% of cities being well fitted to this correlation. With Milano-Italy owing the highest rate of infection as well as the

largest public transportation dependency rate, thus, highest inter-city connectivity among cities within research study. And Cottbus-Germany ranking lowest in rate of infections and is the third least inter-connected city. Numerous studies are conducted and do relate to this research finding, such as Tian et al. (2020) where an analysis was carried out and showed that suspending intra-city public transport was associated with reductions in COVID-19 case incidence within Chinese cities. In addition to the research of (Otsuki & Nishiura, 2016) regarding the Ebola virus outbreak, which concluded that imposed travel restrictions in the early stages of the disease were found to be more efficient in containing its spread than controlling the global spread through international travel restrictions. Another study that was carried out by Goscé and Johan (2018) indicated an existing correlation between the use of public transport and the spread of influenza-like disease in London boroughs. Moreover, following the reactions people have towards certain issues, and that are purely driven out of their natural instincts, almost always indicates something worth investigating. This was apparent in the decline in public transportation ridership around the world especially at the early stages of COVID-19 pandemic which varied across the globe. And out of this research and several other studies regarding the impact of public transportation use on the COVID-19 spread, people's instinct to avoid the use of this mode of transport is proven right.

4.2. Inter-city connectivity (regional-international connectivity)

In addition to the importance of intra-city connectivity shown above, it is essential to also determine a city's regional and international connectivity status especially when dealing with such crisis, for pandemics primarily exists due to firm connections between countries that are becoming stronger by the revolution in the transportation industry, thus, increasing the possibilities of further pandemic occurrence. In order to evaluate the regional-international connectivity level of a city, it was

Table 1
Urban characteristics of study-selected European cities.^{a,b,c,d}

	List of cities	Infection rate/100,000	Modal share %	Regional-international connectivity	Size	Density	Form
England	Exeter	129.6	9	60	125,819	4604	Radial
	Plymouth	140.6	11	40	239,677	4562	Radial
	Portsmouth	151.1	10	40	248,929	5100	Linear
	Southampton	242	14	87	269,750	5038	Radial
	Stoke on trent	271	16	27	278,137	3660	Linear
	Manchester	316	17	87	563,561	4716	Radial
	Sunderland	499.6	13	27	335,415	4466	Radial
	Sheffield	457	30	73	685,365	4508	Radial
	Salford	384	23	73	122,657	3901	Radial
	Germany	Rostock	49.31	17	100	209,191	1153
Cottbus		38.91	10	27	99,678	601.8	Linear
Karlsruhe Stadt		125.2	17	27	283,899	1800	Linear
Augsburg		146.4	16	53	296,582	2019	Linear
Erlangen		231.3	27	14	112,528	1462	Linear
Pforzheim		326.6	17	27	125,957	1285	Linear
Munich		454.5	24	87	1,260,391	4777	Radial
Regensburg		443	11	40	153,094	1893	Grid
Freiburg im Breisgau		422.2	16	27	231,195	1511	Grid
Italy		Palermo	39.84	9	100	648,260	4141
	Reggio di calabrio	52.74	8	67	178,760	757.4	Linear
	Cagliari	59.6	14	80	149,257	1148	Linear
	Livorno	142	8	40	157,024	1498	Linear
	Ferrara	297	15	27	132,195	326.9	Grid
	Bologna	508.6	26	87	390,625	2776	Radial
	Milano	746.6	41	87	1,236,837	7682	Radial
	Turin	702.4	28	87	870,456	6691	Grid
	Genova	659.1	31	87	580,223	2404	Linear

^a City Population, <https://www.citypopulation.de/>.

^b EPOMM: The EPOMM Modal Split Tool, <http://www.epomm.eu/tems/cities.phtml>.

^c MediaCityUK at Salford Quays: A sustainable, transit oriented development, https://www.mangeogsoc.org.uk/pdfs/manchestergeographies/Manchester_Geographies_1_Knowles&Binder.pdf.

^d Population stat, <https://populationstat.com/>

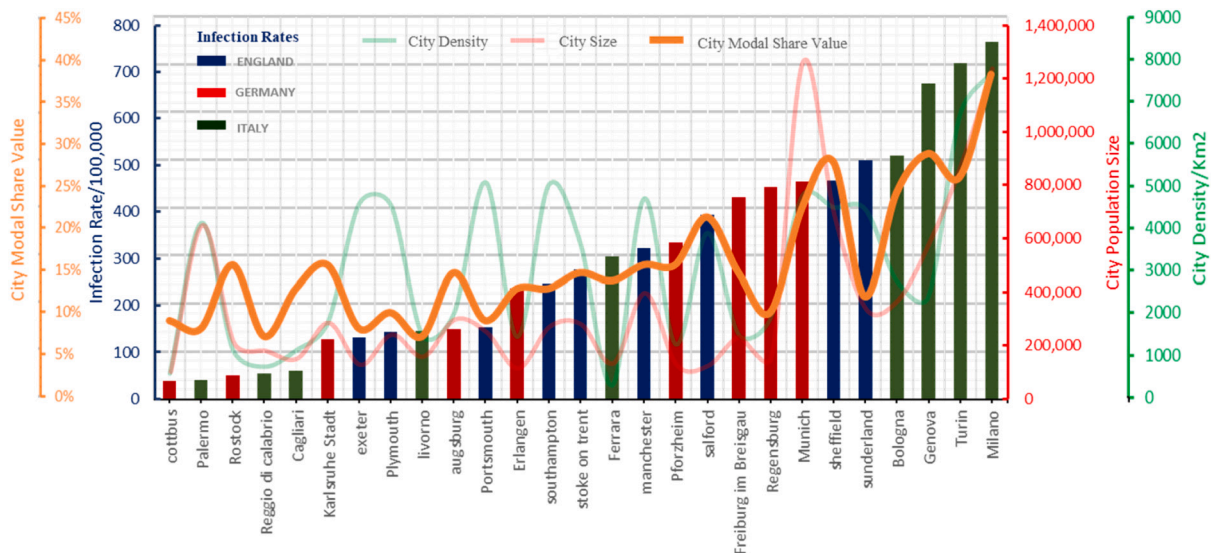


Fig. 1. Modal share values-infection rate. Source: Researcher

important to define the variety in transportation modes that each city possess, as well as scaling them according to their size and importance. Therefore, in this study, regional-international transportation modes were classified and point-scaled as following: Regional road - dependent transportation (cars & buses) *1, nautical transportation*2, Railway transportations*3, local-air dependent transport*4, international-air dependent transport*5, having a sum of 15 when possessing all above-mentioned modes of transportation.

The study of the previous analysis, Fig. 2, has shown an ineffective relation between the city’s regional-international connectivity level and its influence on infection rates despite it being an initiative factor contributing to the current disease spread, and primary cause behind evolving epidemics to a world threatening pandemic. The main probable reason behind this odd outcome is the fact of the globally forced lockdown measures, cutting off all means of international transportation in addition to other travel restrictions on regional levels. However, several studies have examined the efficacy of travel restrictions in containing the spread of the virus and resulted with similar findings. For instance, Chinazzi et al. (2020) applied a global metapopulation disease transmission model to epidemiological data from China. It concluded that

inter-city commute restrictions which was imposed in Wuhan on 23 January 2020 only postponed epidemic progression by 3–5 days. On the other hand, international travel restrictions did help to slow the pace of spread elsewhere in the world until mid-February. According to Tian et al. (2020), imposing travel ban policies on both international and regional levels following the presence of covid-19 are considered ineffective. Thus, it is highly important to aim at actions and precautionary measures when mostly needed, for taking timely actions is the key factor to disease control. However, Zhang et al. (2020) concluded a positive relation between frequent flight departures and number of cases within destined cities in February 2020, which was the early stage of the COVID-19 epidemic control in China.

4.3. Population size

City population size is another denoting factor on infection rate outcomes, for it is of inevitable importance to indicate the number of people residing in each city since the number of people is used as a key measuring unit in infectious outbreaks. And since the research focus is on urban cities, this study selected cities with at least 100,000

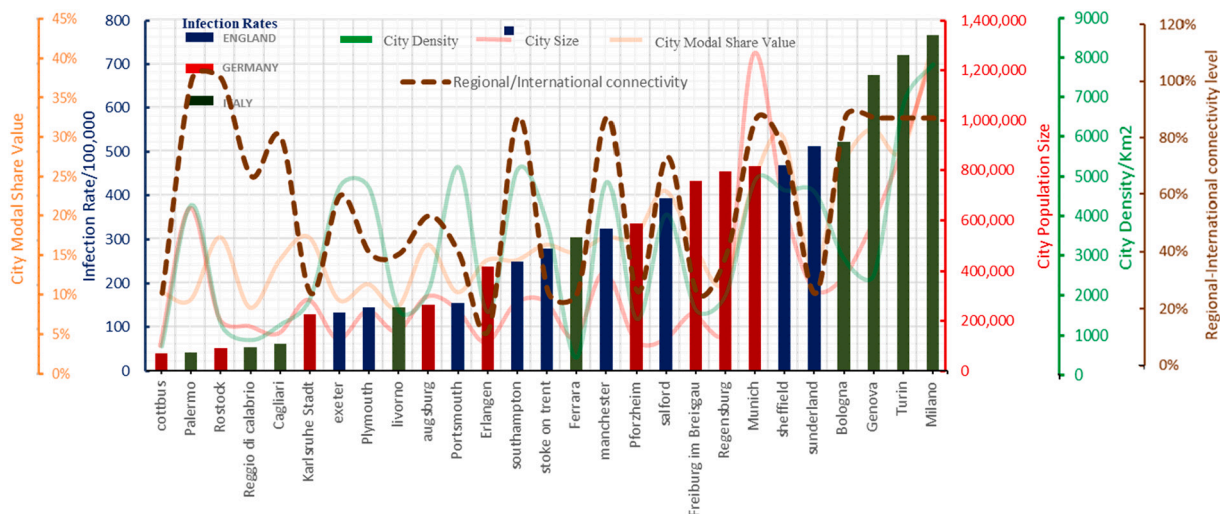


Fig. 2. Regional/international connectivity – infection rate. Source: Researcher

inhabitants. Thus, the following figure, Fig. 3, evaluates the influence of city size on the rates of infections.

The previous figure presents the impact of the city size feature on the city's rate of infection, for it is found to be another semi-influential factor for the above selected European cities reveal a moderate positive correlation. This research finding suits the findings of Stier et al. (2020), as they estimated the growth rates and reproductive numbers of COVID-19 in US cities to reveal that COVID-19 is spreading faster on average in larger cities with the additional implication that, in an uncontrolled outbreak, larger fractions of the population are expected to become infected in more populous urban areas. In addition to a research study that was carried out by Jahangiri et al. (2020), population size was considered as a significant transmissibility factor for coronavirus in Iranian provinces and recommended that cities/provinces with a population of over 1.7 million people ought to imply stricter inspections and more precise controls to their management policy.

4.4. City density

One of the most debatable factors on behalf of many academics and urban planning professionals, is the influence of urban density on rates of infections. Many assumptions were driven by the fact that crowded and large clustered areas raise the likelihoods of infections within them for having people as an easy and effective transmission medium for viral breeding. The following figure, Fig. 4, will aid with the understanding of this factor and put an answer to raised questions.

Regarding City density, the selected European cities in Fig. 4 presents an insignificant impact on the spread of COVID-19. Likewise, Carozzi et al. (2020) associated density with an early arrival of COVID-19 across US counties and found that cities with larger densities may get hit first, but do not necessarily get hit harder. They also claimed that the subsequent spread - once COVID-19 has arrived - is not faster than in smaller towns or sparsely populated peripheries. Other evidence indicates that while cities like Mumbai, New York and London have reported staggering rates of infection, other dense cities like Singapore, Seoul and Hong Kong have managed to keep the worst of the virus at bay (Ratho & John, 2020). According to a World Bank study of 284 cities in China, cities with extremely high population densities—such as Shanghai, Beijing, Shenzhen, Tianjin, and Zhuhai—have had far fewer confirmed cases per 10,000 people (Fang & Wahba, 2020). For Mr. Sameh Wahba of the World Bank stated that it was not population density in itself but the way in which that density was managed that had made cities

vulnerable. Overcrowded settlements with high densities are, thus, the most susceptible in this context. However, Crowding may promote the spread of the disease but differences in demographic or precautionary measures may contain it. This leads to further challenges regarding informal settlements and slums. As overcrowding in these areas make social distancing and self-quarantine impractical interventions since dwellers are considered daily wage earners that must continue to work for their daily living requirements regardless of the measures imposed by the government (Poornima & Prasad, 2020). In addition, these communities, due to their low economic conditions, mostly lack access to basic water and sanitation services, making lifesaving practices like hand-washing a challenge (Muggah & Florida, 2020). And since 1 billion people worldwide currently reside in slums (UNHABITAT, 2016) and are unable to commit to forced restrictions, could quickly lead to an uncontrollable proliferation of the disease among the wider population.

4.5. City form

This study is the first in trying to find whether city forms somehow mediate the spread of contagious diseases. The urban form is mainly observed by how roads and transport infrastructure have been laid (Pie, 2019). Therefore, cities are categorized to either linear, grid or radial shaped urban forms. The following figure represents the impact of city forms on the transmission of COVID-19. Cities with linear morphologies accordingly seemed to encounter the lowest infection rates of this study. In contrast, both grid and radial cities were significantly related with higher rates of infection. This is possibly associated with two main factors. First: the flows of people which is prominently linked with transportation routes. Since linear cities form and develop along an axis which is usually the main transport artery cities are heavily reliant on, people are consequently moving mainly along them. As opposed to radial cities that consists of several axis and transportation routes that spread in all directions and outwards from the city core.

In addition to Grids that also disperse traffic—rather than concentrate it and allow for a tremendous variety of route options (Steuteville, 2019). Accessibility is another possible factor, measured by both city's intra connectivity through various modes of transportation, and city core accessibility. And since this study, along with several others, has proven intra-city connectivity to be the most influential in disease spread. Both radial and grid cities are known by their strong intra city connections and accessibility in contrast to linear shaped cities. City core accessibility is also an important indicator since its known to be home

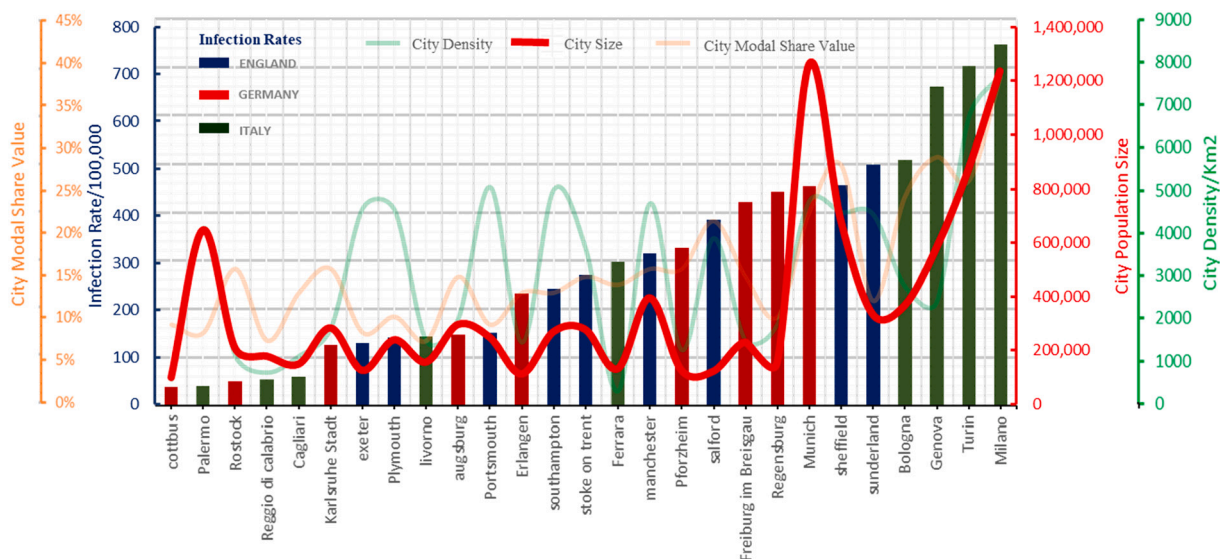


Fig. 3. City size – infection rate. Source: Researcher

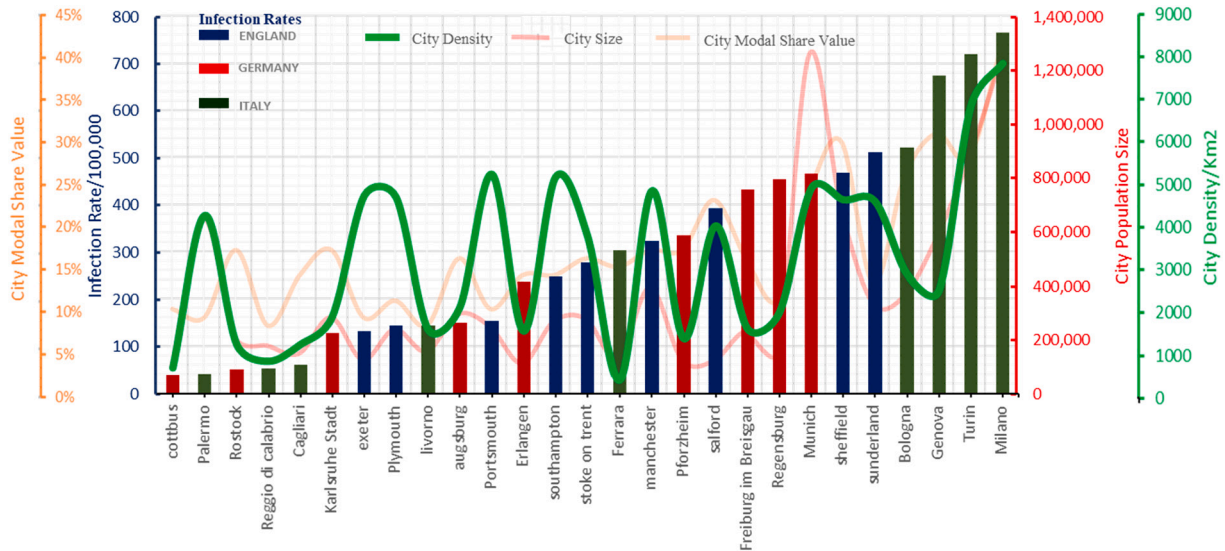


Fig. 4. City density-infection rate.
Source: Researcher

for large social interactions and is thus relatively high in density. Low accessibility of urban center for remote areas are frequent in linear cities especially in those that have not yet acquired the necessary potential for a city of one million people (Antyufeev & Antyufeeva, 2019). City centers in radial and grid cities, on the other hand, are highly accessible. Therefore, this research suggests that radial followed by grid planed cities are the most vulnerable throughout the COVID-19 pandemic while linear cities are the least affected (Fig. 5).

5. Data analysis & results

The main aim of this study is to evaluate the impact of city urban features, discussed in this research, on the degree of disease spread both individually and combinedly. The researchers have therefore conducted advanced statistical techniques (correlation analysis, regression analysis, multi-collinearity, Heteroscedasticity, auto-correlation, normality) for checking study hypothesis using E-views 10 software, ANOVA test using SPSS 24 software.

5.1. Correlation coefficient

The research conducted such analysis to measure the strength of the relationship between each factor and the rate of infections recorded for all case study cities. Therefore, both Pearson and Spearman correlation were applied to the study as shown in Table 2 and Table 3.

A strong positive and statistically significant correlation was identified between rate of infections and Modal share, city size, and city density, respectively. On the other hand, an insignificant correlation was observed by both the city’s regional-international connectivity level and city form.

- There is significant correlation between infection rate (100000) and modal share where p -value = .0000 is less than $\alpha = 0.05$. the correlation is positive strong where the value of Pearson correlation = 0.772 (greater than 0.7)
- There is significant correlation between infection rate (100000) and size where p -value = .0007 is less than $\alpha = 0.05$. the correlation is

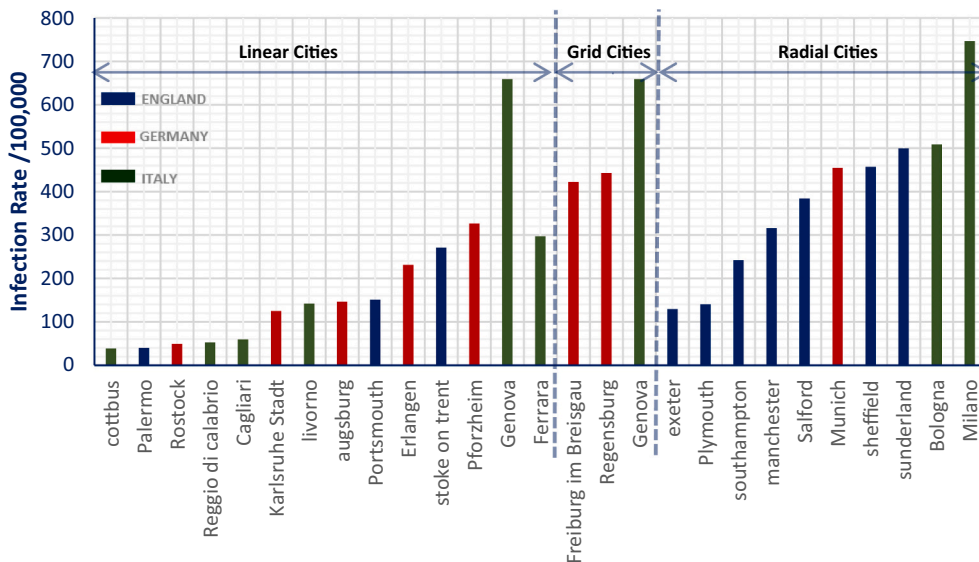


Fig. 5. City form – infection rate.
Source: Researcher

Table 2
Pearson's correlation city characteristics – infection rates.

		Infection rate
Infection rate	Pearson Correlation	1
	Sig. (2-tailed)	
PT modal share	Pearson Correlation	0.772**
	Sig. (2-tailed)	0.000
Regional-international connectivity	Pearson Correlation	0.209
	Sig. (2-tailed)	0.295
City size	Pearson Correlation	0.679**
	Sig. (2-tailed)	0.000
City density	Pearson Correlation	0.501**
	Sig. (2-tailed)	0.008

** Correlation is significant at the 0.01 level (2-tailed).

Table 3
Spearman's correlation city form – infection rates.

		Infection rate	City form
Spearman's rho	Infection rate	1.000	−0.163-
	City form	−0.163-	0.416
	Correlation Coefficient		0.416
	Sig. (2-tailed)		1.000
	Correlation Coefficient	0.416	.
	Sig. (2-tailed)		

Source: Researcher, SPSS 25

positive moderate where the value of Pearson correlation = 0.679 (between 0.4 and 0.7)

- There is significant correlation between infection rate (100000) and density where p-value = .008 is less than $\alpha = 0.05$. the correlation is positive moderate where the value of Pearson correlation = 0.5 (between 0.4 and 0.7)
- There is no significant correlation between infection rate (100000) and regional-international connectivity where p-value = .29 is greater than $\alpha = 0.05$.
- There is no significant correlation between Infection Rate (100000) and city form where p-value = −0.16 is greater than $\alpha = 0.05$.

5.2. Kruskal-Wallis test

The Kruskal-Wallis test merely assesses how the three groups of infection rates (low, medium, high), differ in some way according to the change of city characteristics.

This test found a statistically significant difference between the outcome of the 3 independent groups of infection rates (low, medium, high) according to the applied city features of Modal share, city population size and city density at significance level of 0.01,0.05,0.1 respectively. On the other hand, no statistical differences were found regarding both city form and city regional-international connectivity level (Table 4).

5.3. ANOVA test

In this part, the researcher aims to check differences in infection rate according to city form (radial, linear, grid) using analysis of variance (ANOVA) (Tables 5).

From the previous table we can see that:

There is a significant difference in infection rate according to city form where the value of sig = 0.007 is less than $\alpha = 0.05$. indicating city form to be an influential factor on recorded rates of infections where the mean value of infection rate for grid city is (466.15), the mean value of infection rate for radial city (387.85) and is followed by linear city (176.39).

Table 4
Kruskal-Wallis test.

Ranks	Inf.Rt	Mean rank
PT modal share	Low	8.06
	Mid	14.67
	High	19.28
Regional-international connectivity	Low	14.56
	Mid	11.72
	High	15.72
City size	Low	10.44
	Mid	12.00
	High	19.56
City density	Low	11.89
	Mid	12.11
	High	18.00
City form	Low	14.44
	Mid	14.11
	High	13.44

Test statistics

	PT modal share	Regional-international connectivity	City size	City density	City form
Chi-Square	9.144	1.257	6.787	3.432	0.089
df	2	2	2	2	2
Asymp. Sig.	0.010	0.534	0.034	0.180	0.957

Source: Researcher, Spss 25

Table 5
ANOVA test- city form.

City form	Mean	Standard deviation	F	Sig.
Radial	387.8500	188.34638	6.083	0.007
Linear	176.3923	172.12046		
Grid	466.1500	170.18941		
Total	297.6370	210.10455		

5.4. Multiple - linear regression analysis

Linear regression analysis is used to measure the combined effect of city characteristics; city form, city size, regional-international connectivity, modal share, city density, on the infection rates recorded in all three countries.

From Table 6 we can find that:

- The model is significant (where the value of prob. (F-statistic) is less than $\alpha = 0.05$) which means that at least one independent variable has effect on dependent variable (infection rate).

Table 6
Multiple linear regression analysis.

Variable	Coefficient	Std. error	t-Statistic	Prob.
C	−17.56128	82.25586	−0.213496	0.8329
City density	0.023046	0.018180	1.267673	0.2182
PT modal share	16.49201	4.109561	4.013084	0.0006
Regional international connectivity	−1.434695	1.122264	−1.278394	0.2144
City size	9.46E-05	0.000142	0.664951	0.5130
R-squared	0.663746	Mean dependent var		297.6370
Adjusted R-squared	0.602609	S.D. dependent var		210.1045
S.E. of regression	132.4477	Akaike info criterion		12.77583
Sum squared resid	385,932.8	Schwarz criterion		13.01580
Log likelihood	−167.4737	Hannan-Quinn critier.		12.84718
F-statistic	10.85668	Durbin-Watson stat		1.532854
Prob(F-statistic)	0.000052			

Table 7
Multicollinearity test.

Variable	Coefficient variance	Un-centered VIF	Centered VIF
C	6766.026	10.41378	NA
City density	0.000331	6.870329	1.890188
PT modal share	16.88849	9.894879	1.747951
Regional International connectivity	1.259476	8.086970	1.465550
Size	2.02E-08	7.388295	3.131609

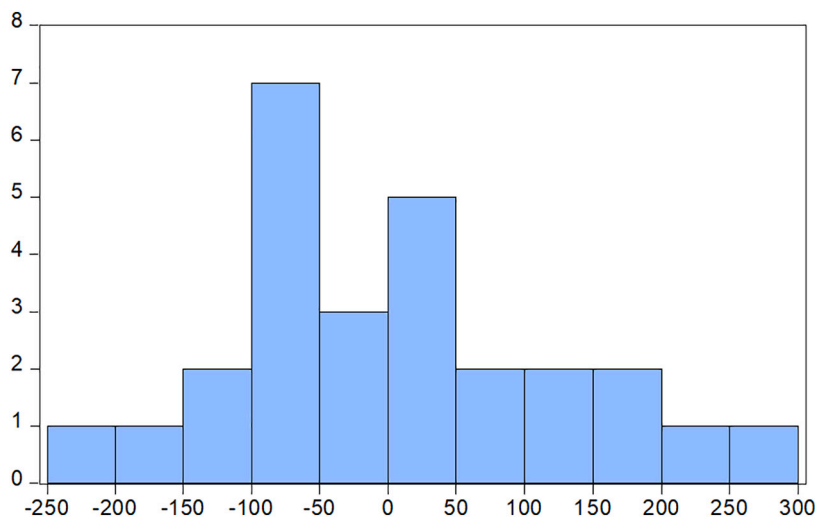
Table 8
Auto-correlation test.

Breusch-Godfrey Serial Correlation LM Test			
F-statistic	0.800873	Prob. F (2,20)	0.4628
Obs*R-squared	2.002021	Prob. Chi-Square (2)	0.3675

Table 9
Heteroscedasticity test.

Heteroscedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	1.024580	Prob. F (4,22)	0.4165
Obs*R-squared	4.239915	Prob. Chi-Square (4)	0.3745
Scaled explained SS	2.200575	Prob. Chi-Square (4)	0.6989

- The independent variables (density, modal share, regional-international connectivity, size) managed to explain 60.2% of the variations in dependent variable where the value of Adjusted R-squared = 0.602.
- There is no significant effect of density on infection rate where the value of prob. = 0.218 is greater than $\alpha = 0.05$.



Series: Residuals	
Sample 1 27	
Observations 27	
Mean	4.00e-14
Median	-28.19517
Maximum	278.4352
Minimum	-220.6706
Std. Dev.	121.8342
Skewness	0.499417
Kurtosis	2.563476
Jarque-Bera	1.336752
Probability	0.512540

- There is significant effect of PT modal share on infection rate where the value of prob. = 0.0006 is less than $\alpha = 0.05$.
- There is no significant effect of regional-international connectivity on infection rate where the value of prob. = 0.214 is greater than $\alpha = 0.05$.
- There is no significant effect of size on infection rate where the value of prob. = 0.513 is greater than $\alpha = 0.05$.

Four assumptions are tested to examine the regression robustness as follows (Tables 7 to 9):

5.4.1. Multi-collinearity

The multi-collinearity problem is related to independent variables; it means that the independent variables are highly correlated. This problem causes biased results; it can be measured through using Variance Inflation Factor (VIF). VIF values less than 10 means that there is no multi-collinearity problem.

From the previous table we can see that there is no multi-collinearity problem where values of centered VIF are less than 10.

5.4.2. Auto-correlation test

The auto-correlation problem is related to model residuals; it means that model residuals are highly correlated with each other. This problem causes unreliable results; it can be tested using Breusch-Godfrey Serial Correlation LM Test.

From the previous table we can see that there is no auto-correlation problem in residuals where Prob. Chi-Square (2) = 0.3675 which is greater than $\alpha = 0.05$.

5.4.3. Heteroscedasticity test

The heteroscedasticity problem is related to model residuals; it means that model residuals variances are not constant across time. This problem causes inconsistent results; it can be tested using Breusch-Pagan-Godfrey Test.

From the previous table we can see that there is no heteroscedasticity problem in residuals where Prob. Chi-Square (4) = 0.698 which is greater than $\alpha = 0.05$.

5.4.4. Normality test

The normality assumption is related to model residuals. It means that the residuals follow normal distribution. When normality assumption is existed means that the model is good. The normality assumption will be tested using Jarque-Bera test.

From the previous graph we can see that; there is normality in residuals, where the probability = .512 is less than $\alpha = 0.05$.

6. Discussion

Many of the developments in urban planning through the history of cities are the direct results of pandemics and health crisis (Almeida, 2020). London’s mid-19th sanitation systems was one of many iconic developments in response to public health crisis such as cholera

outbreaks. Now COVID-19 is joining a long list of infectious diseases, like the Spanish flu of 1918 in New York and Mexico City or the Ebola Virus Disease in West Africa in 2014, and is likely to reshape cities and imply new strategies in urban planning (CityLab, 2020). And since cities are shaped by people, their densities and size and movement are necessary to trace during such crisis. This study proved that urban factors in this regard, have a significant effect on COVID-19 spread some of which were individually significant than others and have a direct impact on the rates of infections. Intra-city connectivity, referred to as the PT modal share value which measures connectivity within cities through public transport, is considered the most influential and had the highest contribution to COVID-19 spread among other study related factors. Through the regression model, it is found to have a significant effect on infection spread with p value = .0006 < 0.01. Similarly, this finding is also supported by other studies (Tian et al., 2020) that also runs a regression model to find that suspending intra-city transport during the first week of the pandemic in Chinese major cities helped reduce total numbers of infected cases with a significance level of $p < .01$. On the other hand, an analysis of public transit ridership in multiple US cities shows no correlation with the rise or fall of local COVID-19 cases. However, while other independent study factors show positive correlations with infection rates (0.68 - $p < .01$), (0.50 - $p < .01$), (0.21 - $p > .05$) according to their population size, density, and regional-international connections respectively, they are considered insignificant when combined through the regression model. Other studies backed up these results and have found density and international connectivity not influential factors. Carozzi et al. (2020) found that density has affected the timing of the outbreak in US counties, with denser locations more likely to have an early outbreak rather than number of cases or deaths. Another study conducted in US counties however has found otherwise, counties with greater population density have greater rates of transmission of SARS-CoV-2, likely due to increased contact rates in areas with greater density (Therese, Laura, & Nichols, 2020). Kadi and Khelifaoui (2020) also discovered that the spread of COVID-19 in Algeria is increasing with population density. Many found that international connections merely contributed to disease spread later through the pandemic, and that taking timely actions is the key factor to disease control. As Chinazzi et al. (2020) concluded that travel quarantine around Wuhan has only modestly delayed the spread of disease to other areas of mainland China. Nevertheless, Zhang et al. (2020) found otherwise as a positive existing correlation was indicated by frequent flight departures and number of cases within destined cities in February 2020 in Chinese cities. Population size however showed contradicting results. Although showing a statistically significant correlation with infection rates, it was insignificant among other variables in the regression model. As opposed to Stier et al. (2020), Jahangiri et al. (2020) found that population size is a critical factor in epidemiological outbreaks and faster growth of COVID-19 was reported in cities with larger population within both US and Iranian cities. City form also has a share in COVID-19 transmission according to this study. The conducted ANOVA test reveals a significant difference in infection rates in respect to the three categorical city forms: radial, grid, and linear, $\text{sig} = 0.007 < 0.01$. Both radial and grid formed cities encountered majority of cities with higher infection rates in contrast to linear cities. Moreover, a robust and statistically significant effect was identified through the performed regression analysis of all the study factors combined and have managed to explain 60.2% of the variations in dependent variable where Adjusted R-squared = 0.602 and p value = .0005 < 0.01. And since urban planning is considered an interdisciplinary field that includes social science and deals with human behaviors that are hard to manage and predict, this effect is considered significant (Frost, 2018).

7. Conclusion

While study factors are proved to have a significant impact on COVID-19 spread when combined. Intra-city connection through public

transport is considered the most significant factor among all. Therefore, and upon research finding, public transportation planning should earn higher shares of interest for future research. As timely actions are essential and required before people start considering long-term switches to private vehicles and abandoning public transport when their travel needs are not met. This is also essential for achieving low-carbon and inclusive urban development. Nonetheless, several effective contributions were offered to limit disease spread and reduce crowding, many of which include: reducing capacity on individual services, increasing the frequency of services during busier periods, promoting online ticketing, reducing number of stops by encouraging walkability and other modes of active transport such as bike sharing. Thus, more investment in cycling and pedestrian infrastructure is necessary for active transport modes have proved more effective in meeting mobility demands of citizens during pandemics. It is necessary to note that other probable contributing factors are also important when considering outbreaks in urban planning, such as public health precautionary measures, imposed management policies, and socio-economic factors. However, due to research limitations, retrieving such data for a city level study with a relatively large sample size was inaccessible. Thus, future national scale studies may stand an opportunity to fully incorporate the effect of such factors on disease spread in the field of urban planning.

Declaration of competing interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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