An Analysis of the Impact of Mobility on the Spread of the Covid-19 Pandemic

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***Abstract*—COVID-19 pandemic has rapidly spread globally and a restriction of human mobility is still the only dynamic way that is undertaken by governments to control the transmission of the virus. Therefore, the purpose of this study is to examine the impact of mobility on the spread of COVID 19. This research used driving, transit, and walking as mobility trends of real-time data to examine the correlation between human mobility and the spread of COVID 19 with Pearson's correlation. The study collects data from four countries (Australia, Germany, The United Kingdom and The United States of America) which are among the countries with the highest COVID-19 confirmed cases in the world. The findings showed that there is a positive correlation between mobility and the spread of COVID 19 and therefore, indicating that the increase in mobility is positively associated with the spread of COVID 19. In addition, the findings showed that the degree of citizen's commitment to national lockdown is a determining factor for limiting the spread of COVID 19. The degree of citizen's commitment to public orders of closure is the main influential factor to reduce the epidemic spread rather than the closure decision. More public awareness is needed to increase the sense of responsibility and commitment among citizens.**

Keywords*— COVID-19 pandemic, human mobility, lockdown, epidemic spread, Pearson's correlation, mobility trends, apple trends

I. INTRODUCTION

With GPS trajectories, many people have started recording and sharing their movements within web-based communities. It has enabled individuals to share their route tracing, travel experiences, sports activity analysis, lifelogging, etc. These trajectories can produce enormous business opportunities in geographical navigation and recommendation system, and in fact, trajectories of human mobility also play a significant role in numerous research fields such as epidemic modeling, traffic planning, mobile computing and disaster response [1].

A sound understanding of mobility through different economies might be helpful within the creation of public dynamics to enhance human development in fields such as modeling the epidemic spread, social sciences and transportation alternatives. In recent years, a wide range of studies using different applications have resulted in various models like modeling the spread of viruses [2].

The authors of [3] had analyzed the relationship between human mobility and urban socio-economic status in which they presented indices of mobility that are best associated with socio-economic levels, and they created a model for predicting the socio-economic level from cell phone traces.

Although exploring human mobility is based on default science methods but the collection of data involved tedious manual travel surveys, interviews space-time and diaries. The development of sensors that can detect location has significantly modified the opportunities for accurate statistics on the movements of human beings. This has led to the promotion of various methodological advances that can recognize human movement patterns and their effects on the spread, persistence and evolution of infectious diseases [4]. Human culture has never been in combat with infectious diseases. Diseases such as the Ebola virus, AIDS, influenza, pestilence, plague, SARS, avian flu, and cholera spread had killed more than tens of thousands of people in many regions around the world [5]. A majority of studies have acknowledged the impact of mobility on epidemics spread [6], [7]. Specifically, COVID-19 was first registered at the end of 2019 in Wuhan, China. The World Health Organization (WHO) announced it as a "Public Health Emergency of International Concern" on January 30, 2020, and declared it as a pandemic on March 11, 2020. The disease has been reported in more than 200 countries and continues to spread around the world. According to WHO, up to March 23, 14,509 people had succumbed to death with 1,727 new deaths while 332,930 confirmed cases of Coronavirus contamination with 40,788 affirmed cases were reported [8]. This pandemic has demonstrated the interconnected nature of the world and that, no one is safe until everyone is safe. As the number of cases increases, the policymakers and authorities have use mobility restrictions that were, and still, the best way to monitor viral transmission.

Due to the rapid and dangerous spread of the pandemic in the USA, the absence of a centralized policy and only 'Stay-at-home' State Authorities' Instructions, the author of [9] investigated how the prevalence of new infections in 25 counties in the USA was influenced by social distance. This was measured by the relative change in human mobility by fitting a statistical model for each county. Badr found that the decreasing COVID-19 case growth rate patterns were strongly correlated with human mobility for the USA's most affected counties. Searchers of [10] uncovered the behavioral parameters of change in mobility patterns of major cities in Canada and the people's contentment about how infectious the disease is at the level of compliance with public orders, using the concept of an individual's activity space (encompassing all the locations that an individual interacts with over time). The research discussed on how mobility patterns show the effectiveness of lockdown policies to control the infectious disease transmission. The Centers for Disease Control and Prevention (CDC) defined public reaction as Nonpharmaceutical Interventions (NPIs). Even under strict restrictions, the degree of social distancing was inferred as being bound by choice, which is related to people's beliefs about the authority's public order regarding how grim the crisis is.

In a recent study, authors [11] found that enforcing restrictions on gatherings and cancellation of public events which limit human movement in numerous and crowded locations, have the greatest impact on the pandemic containment, in terms of statistics and levels of effect. Additionally, schools and workplaces closures as well as stay-at-home requirements have contributed to a decrease in the occurrence of infections. Closures of public transport and controls of international travel had also contributed to a decline in new infections.

Apple and Google as global communities had responded to COVID-19 by cooperating with public health officials with the use of products such as Google and Apple Maps that could facilitate critical decision-making to combat the disease. Hence, the use of these community reports and WHO data can reinforce our finding on the link between mobility and viral transition.

This paper investigates how effective restrictions of mobility trends could control the transmission of SARS-CoV-2, as we accessed mobility data through Apple trends daily reports and WHO's epidemic data. In the next section, we have presented several related works that are associated with our work, and then followed by the subsequent section where we describe the methodology and data used in our work to examine the relationship of mobility data with COVID-19 spread. The methodology section is followed by the results section where we have presented some explanatory graphical charts to show people's commitment to the national closure and their impact on the increase or decrease of the infections. This serves as the main contribution of our study. The last section presents the discussion and conclusion of this study.

II. RELATED WORK

In this section, we present some relevant works focusing on human mobility and the current COVID-19 transmission.

Authors of [12] in their modeling study had built a modified susceptible–exposed–infectious–recovered (SEIR) compartmental transmission model for COVID-19 to predict the epidemic curve shape of the disease in Shenzen, China by combining the effect of human mobility with the spread of infection. Data from mobile phones were obtained from the providers of mobile phone services in Shenzhen, covering working days (Monday to Friday) from January 10 to March 10, 2019. The daily cases of Coronavirus in the city were obtained from the Shenzhen Local Government website. The study was distributed through ten regions of Shenzhen. The policy of mobility restriction leads to a decrease in the virus transmissibility by 25% to 50%. The model demonstrated the impact of different types of mobility restrictions in mitigating the outbreaks of the disease. According to the authors, the model could assist policy makers to determine the best combinations of human mobility restrictions during the outbreak for assessing the potential positive impact of mobility restriction on public health in the light of the potential negative societal and economic impacts. The results were presented graphically in their study.

The authors of [13] developed a multiple linear regression model to identify the effect of mobility behaviors in the COVID-19 spread in Italy. The aim of the study was to examine the disease transmission in the country and to discuss the influence of citizen movement within the spread of the epidemic. The daily reports of the positive cases between February 21 and May 5, 2020 were acquired from the Italian Ministry of Health along with the data of Italian national census relative to 2019, while the COVID-19 mobility data were obtained from the Italian Transport Ministry. The findings indicated that the number of new infections in a day was associated with the trips performed three weeks prior. For this case study, a 21-day threshold is accepted as a kind of positivity detection time measure. In other words, quarantine for mobility restriction is commonly set at 14 days. Underestimating the policy of containment and slowdown in implementing restrictive actions can possibly result in more infections and deaths by COVID-19.

Askitas [11] developed a multiple-events model as an econometric framework to study the influence of mobility restriction and lockdown policies especially the closures of public transport, international travel controls, cancelation of public events, workplace and school closures, in addition to the requirements of stay-at-home as well as the time spent at these places on the incidence of COVID-19 new infections. The study involved 135 countries which vary in their intensity, type and timing using the epidemic data from the European Centre for Disease Prevention and Control (ECDC) and the mobility data reports from Google. They found that enforcing restrictions on human movements in numerous and crowded areas have the largest impact to curb the epidemic spread.

The authors of [14] organized a study to investigate the impact of lockdown during the COVID-19 outbreak on human mobility using the change of spatial time series over various union territories (UTs) in the States of India. This study also figured out the difference before and after the lockdown. Data were collected from February 15 to April 30, 2020 from Google COVID-19 Mobility Reports, 2020; the reports included various places like groceries and pharmacies, transit stations, retail and recreation, parks, groceries and pharmacies, residential and workplaces. During their study, they used conditional formatting technique such as color ramps (red, yellow and green) where the red color indicates a high percentage of decreased mobility from baseline, while yellow designates a moderate percentage of decreased mobility and green implies a very low percentage of mobility decreased from baseline. They have also employed the interpolation mapping techniques of "spatial inverse distance weighted" (IDW) to show pre- and post-lockdown human mobility trends due to COVID-19. The results showed that grocery and pharmacy, workplaces, transit stations, retail and recreation, as well as visits to parks mobility dropped by -51.2%, -56.7%, -66%, -73.4%, and -46.3% respectively. As people mostly opted to stay at home during the lockdown, the residential places mobility visits raised by 23.8%. Hence, the result of the mobility trends over time can be used in public health strategies to reduce COVID-19 transmission.

Tobías [15] had collected data of SARS-CoV-2 between February 24 and April 5 from the Italian and Spanish Ministries of Health websites. He used an interrupted time-series to evaluate the change in trends of incident diagnosed cases based on the intensive care unit (ICU) admissions before and after the two countries' respective lockdowns, and analyzed with quasi-Poisson regression using Stata Release 16. He found that the daily percentage of all the incidence outcomes before the lockdown had increased and Spain recorded higher percentages (38.5% for diagnosed cases, 26.5% for ICU admissions and 59.3% for deaths) compared to Italy (21.6%, 16.7% and 32.8% respectively). In Italy during the first lockdown, the diagnosed cases were reduced by 42.1%, ICU admissions by 77.8% and deaths by 58.2%, whereas in Spain, the reduction was even higher; diagnosed cases had dropped by 69.1%, ICU admissions by 66.8% and deaths by 77.8%. During the second lockdown, both countries showed reduction in daily diagnosed cases, ICU admissions and deaths.

The authors in [16] had also analyzed the association of mobility trends with the number of infected people with Coronavirus for 144 countries. Schengen countries were coded as 1 and 0 for otherwise using negative binomial regression (NBR) analysis based on the Poisson-gamma mixture distribution. They focused on airports number, the Schengen system, and the volume of air travel. Data on Coronavirus infection were extracted from WHO and mobility data was obtained from the World Development Indicators. The results showed a positive correlation between that the increasing number of infections was positively correlated with the magnitude of airline travel. They also found that Schengen countries which have a higher percentage of elderly people and a higher population density were reported with higher COVID-19 cases compared to other countries. In addition to that, countries with a greater number of airports were linked to a higher number of infections due to the epidemic.

III. METHODOLOGY

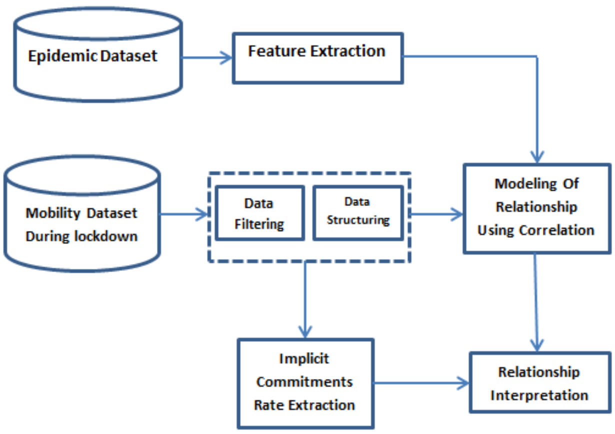

Fig. 1. The methodology diagram

This study is mainly focused on countries that had registered a high incidence of COVID-19 infections. By using WHO and Apple mobility data, we determined the impact of human mobility on the viral transition through several steps with Microsoft Excel Worksheets and Python programming language so as to understand the correlation between people commitments towards closure public orders and the current COVID-19 spread.

A. *Data collection*

We used reports provided by Apple Company for daily mobility trends of walking, driving and transit [17]. The reports reflected the requests for directions in Apple Maps. There is an existing privacy setting; Apple does not have a search history for individual movements.

We collected COVID-19 data of daily reports from WHO official website [8]. The data covered the number of people infected with Coronavirus for the year 2020.

B. *Data Analysis*

We analyzed the data using Microsoft Excel worksheet and Pearson's correlation (with python code) in order to find the association between mobility trends and disease spread during national lockdowns which started in different periods of March 2020 for the following countries: Australia, Germany, The United Kingdom and The United States of America. The following steps were carried out in the analysis of data in this study:

- Feature Extraction (FE): the epidemic dataset requires exclusion of death and recovery cases. Thus, we only focused on new infections.
- Data filtering: The filtering process in our work includes choosing a specific region of interest from the huge Apple mobility trends that consist of data for most regions and countries around the world. We also need to aggregate the data for mobility trend for all regions within a country so that it is compatible with data from WHO for the countries' data.
- Data structuring: Structuring our data revolve around the gathering of information like a declaration of closure as well as handling the little bit of gaps within Apple data by taking the average of two dates around the missing one to have a full data that explains the daily trends clearly. Then, it is followed with the gathering of COVID-19 and mobility trends data with closure dates and arranging them into separate files in .csv format as preparation for assessing the relationship between mobility and disease spread based on the calculation of Pearson's correlation coefficient. The range for correlation coefficient is between–1 and +1, with +1 signifying a perfect positive relationship while -1 reflects a perfect negative relationship and a zero value indicates that there is no association at all. A correlation between two variables such as x and y based on the Pearson correlation coefficient is determined using the calculation formula as shown below:

$$r = \frac{\sum_{i=1}^{n}(x_i - x)(y_i - y)}{\sqrt{[\sum_{i=1}^{n}(x_i - \bar{x})^2]\ [\sum_{i=1}^{n}(y_i - \bar{y})^2\ ]}} \quad (1)$$

Whereby: r is the correlation coefficient; n is the sample size; x_i and y_i are the i^{th} individual values of x and y variables in a sample; and $\bar{x}$, $\bar{y}$ are the mean of the values of the x and y variables [18].

For this study, the selected countries were among those with the highest number of COVID-19 confirmed cases in the world. The first wave of COVID-19 cases for The United Kingdom was in spring, 2020 and the first national lockdown was on March 23, 2020 [19]. March 19, 2020 saw the first closure of Germany which lasted for 14 days. Australia's lockdown announcement was on March 21, 2020. A total of 32 USA counties out of 50 were closed on March 28, 2020 [9]. To improve our results, we tried another periods of time where the mobility trends of (driving, transit, and walking) exceeded the base of apple trend (100) which indicates an obvious increase in mobility and thus, showing a correlation of a strong connection with the disease transmission.

IV.THE RESULTS

Based on the established methods described in the literature [20] – [25], we run the model for one month starting from the full lockdown for Australia, UK and the USA and 14 days for Germany during its first lockdown period. In consideration of the factor of disease incubation period, we assumed a shifting of three days for Australia, UK and The USA and a day for Germany to measure the citizens' commitment to the lockdown. This was calculated using statistical metrics by Microsoft Excel worksheet. Table I shows the association between human mobility trends (driving, transit, walking) and disease spread in the four countries based on Pearson's correlation coefficient as well as the citizens' compliance rate with closure.

Table I. Person's correlation of mobility with COVID-19 new cases and citizen's commitment to public orders of closure

Country	Closure Dates	Citizen's Commitment Driving Transit Walking	Correlation Driving Transit Walking
Australia	21.3.2020 - 19.4.2020	0.48 0.74 0.54	0.299 0.603 0.270
Germany	19.3.2020 - 17.4.2020	0.54 0.56 0.53	0.548 0.457 0.659
UK	23.3.2020 - 21.4.2020	0.62 0.82 0.56	0.503 0.061 0.571
USA	28.3.2020 - 26.4.2020	0.25 0.61 0.37	0.342 0.011 0.404

During the study period, the Pearson's correlation coefficients showed positive values with high citizens' compliance. As shown in Fig. 2, Fig. 3, Fig. 4 and Fig. 5, mobility decreased during the lockdown and this clarified that people's commitment to closure as shown during the one-month lockdown period and a month before that for Australia, Germany, The United Kingdom and The United States of America respectively.

The second part of our analysis revolves around the opposite of closure. The results in Table II show that with the increase of mobility trends, new infections also increased. This result reinforces our conclusion regarding the strong association of human mobility with viral transmission.

Table II. Person's correlation of mobility with COVID-19 new cases and the number of new cases at the beginning of the three months of the study and the end of it

Country	Out of Lockdown Date	New Cases	Correlation Driving Transit Walking
Australia	28.5.2020 - 28.8.2020	6 – 104	0.223 0.397 0.343
Germany	1.6.2020 - 28.8.2020	333 – 1479	0.466 0.487 0.315
UK	25.6.2020 - 22.9.2020	886 – 4368	0.278 0.751 0.633
USA	1.5.2020 - 29.7.2020	333 – 1479	0.523 0.525 0.467

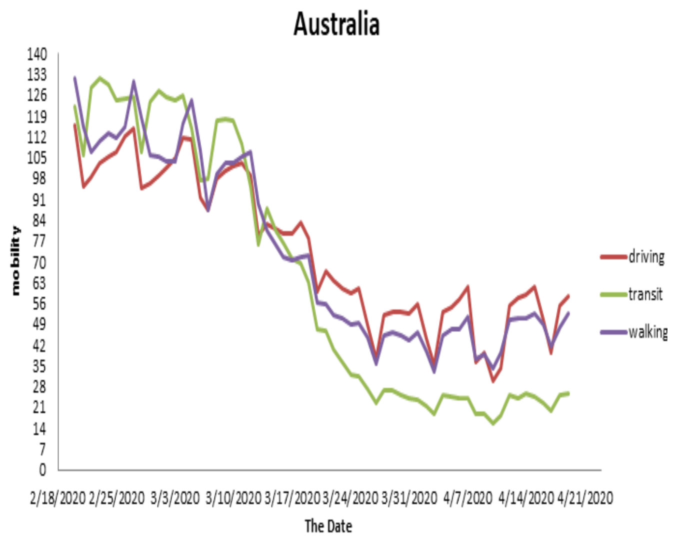

Fig. 2. Mobility trends before and during national lockdown for Australia

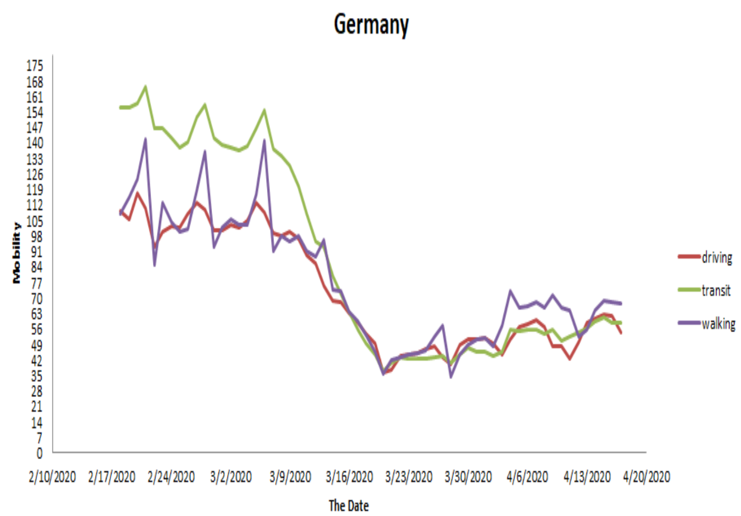

Fig. 3. Mobility trends before and during national lockdown for Germany

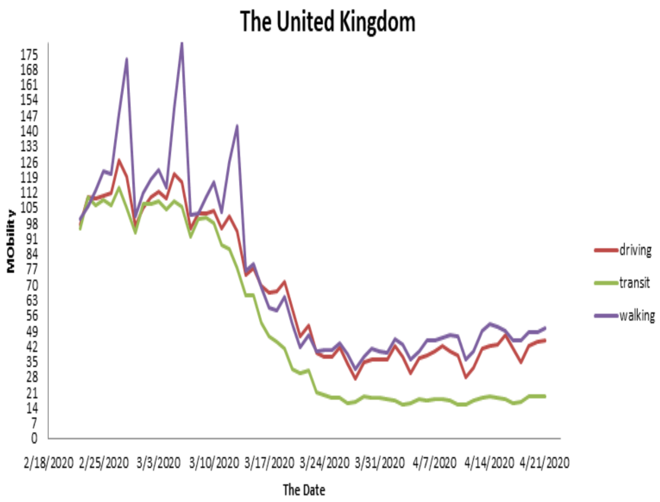

Fig. 4. Mobility trends before and during national lockdown for The United Kingdom

Fig. 5. Mobility trends before and during national lockdown for The United States of America

IV. CONCLUSION AND DISCUSSION

This study examined the association between mobility and the spread of COVID 19 in four selected countries. Data were collected using Apple trends as well as from WHO. A correlational analysis was conducted and the findings showed that the degree of citizens' commitment directly influences the reduction of new infection growth rate, whereby it was observed that whenever citizen's commitment was high, the correlation increased. Therefore, this indicates that the lockdown policy by itself was not enough to restrain the outbreak of the disease, but the compliance to the closure national orders plays the more significant role to reduce number of new infections.

Furthermore, it was noted that there is a high correlation between increasing human movements and disease transmission, which is observed during the second half of the year when Apple mobility trends reached 200 and sometimes more. During that period, the correlation showed a high positive relationship with the number of COVID-19 new cases. From all the above conclusions, we gathered insights on why mobility restriction has been used globally to control viral transmission all over the world.

Understanding the dynamics of stay-at-home and social distancing public orders has helped to reduce the growth rates of COVID-19 infections. Therefore, policy makers are recommended to increase the awareness for practicing social distancing and staying at home, as well as increasing the commitment of citizens to halt the spread of COVID 19. There are limitations of this study as the focus was only on four countries and only the available data from Apple and WHO were considered. The study is also limited to investigate the impact of mobility on COVID 19 new infection cases only. Other than that, other mitigating factors such as handwashing and using face masks were not considered in this study. Therefore, these limitations could set the direction for future work.

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