Human Mobility Patterns and Its Cross-Correlation with the COVID-19 Transmission in Jakarta, Indonesia

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Abstract. The novel coronavirus disease (COVID-19) has been rapidly spreading and causing a severe health crisis in Indonesia. In the absence of medically proven vaccines, official authorities commonly adopt a social control approach under the strict public order. The Indonesian Government is no different, which imposed a large scale social restriction as an intervention strategy in Jakarta and other major cities. In this paper, we aim to quantify the correlation between human mobility and the daily new cases of COVID-19 which are further divided into two main distinct patterns: weekdays and weekends. We utilized the big data sources presented by reputable online service providers include Apple, Waze, and Google in terms of the reported daily mobility patterns. The mobility patterns include driving and walking activities as well as the movement trends across different public places such as retail and recreation, pharmacies, groceries, parks, etc from March 1 to July 31, 2020. To capture the real growth rate of COVID-19, we use the official data reported by Governmental Disease Response Acceleration Task Force. Our cross-correlation analysis revealed that in Jakarta (province-level) and Indonesia (country-level), the COVID-19 case daily growth rate is correlated with the human mobility patterns of driving and walking activities on both weekends and weekdays time. Our work put the additional insight in supporting the importance of social distancing as an effective mitigation strategy to combat the coronavirus outbreak.

1. Introduction

Since the first case of the novel coronavirus disease (COVID-19) reported in December 2019 in Wuhan, China, the world has been suffering from the pandemic that affects people’s daily life [1]. The SARS-Cov-2 virus, the strain coronavirus that causes COVID-19, has been known to easily transmit and infect a massive number of people [2, 3]. The clinical symptoms of COVID-19 are similar to those of SARS and MERS which may generate a severe illness in the respiratory system [4, 5].

Indonesia is one of the countries in the world with the highest proportions of COVID-19 related death [6]. With the fourth-highest number of population in the world, Indonesia is predicted to suffer in the long-term period and massive scale [5]. The first confirmed of two cases in the country, according to the Indonesian government official report, was found on March 2, 2020 [3, 5, 7, 8]. As of October 9, the pandemic in the country has worsened with the reported 320,564 cases and 11,580 deaths [9]. The Province of Jakarta, the capital of Indonesia, is admitted as the epicenter of the pandemic with the highest reported case [9].
Government authorities in many countries are commonly known to impose physical distancing and movement restrictions policies in response to the rapid spreading of the virus [4, 10–12]. For instance, the Indonesian government has called for large-scale social restrictions in Jakarta since April 10, 2020, based on the Regulation of Jakarta Governor No 33/2020 [13]. The regulation enforces the closure of universities, schools, shopping centers, tourist attraction venues, and many other public facilities that could potentially attract public gatherings. Human mobility data offers essential information as to whether people are eagerly following the regulation by reducing their out-of-home activity, long-distance traveling, and frequent social contact to limit the exposure of COVID-19.

In this paper, we aim to investigate the human mobility patterns during the COVID-19 pandemic and its correlation with the change in the number of COVID-19’s daily cases. The COVID-19 case in Indonesia and the province of Jakarta are taken as the case study. We analyze the daily mobility data patterns from Apple, Waze, and Google which are divided into two types, namely weekdays and weekend patterns.

Our findings from the cross-correlation analysis show that the COVID-19 case daily growth rate is correlated with the human mobility patterns of driving and walking activities in both weekends and weekdays time of Jakarta (province-level) and Indonesia (country-level). These findings provide a supporting insight into the importance of strict mobility restrictions as one of the effective mitigation strategies to scale down the coronavirus outbreak.

2. COVID-19 in Indonesia
The COVID-19 was officially reported to enter Indonesia on 2 March 2020, after two patients tested positive for the virus. One month after, by 9 April, the spreading of the pandemic had already covered all 34 provinces in the country, where the Province of Jakarta as the capital holds the highest confirmed positive cases [9]. Indonesia, being the world’s fourth most populous country is predicted to suffer greatly from COVID-19 and in a longer period, when compared to other less-populous countries [14]. A coordinated response policy is thus undoubtedly important.

The first significant policy in response to the pandemic is the establishment of the Task Force for Rapid Response to COVID-19, known as Gugus Tugas Percepatan Penanganan COVID-19 in the native language. This task force is aimed at better inter-department response strategies and coordination. A consolidated statistics and information of the pandemic produced by the task force are continuously updated on a daily basis [9]. Figure 1 shows the spread of the pandemic in Indonesia across the provinces confirmed by the task force [9, 15].

3. Data
The data used in this paper were collected from multiple sources that are publicly available. The period of study is from 1 March 2020 to 31 July 2020. The main indicators of human mobility pattern used in this paper are taken from three big data providers:

- the COVID-19 Community Mobility Reports provided by Google [16],
- the Mobility Trends Reports provided by Apple [17],
- the COVID-19 Mobility Reports provided by Waze [18].

The Google mobility data [16] is reported based on the anonymized location-based statistics to measure the percent changes in the frequency of visits to several categories of locations on a given day, as compared to a baseline number for that day of the week. The location categories are decomposed into the retail and recreation, grocery and pharmacy, parks, transit stations, workplaces, and residential places.

On the other hand, the Apple mobility statistics [17] provides the relative number of directions requests sent recorded on the Apple Maps, compared to a baseline value on 13 January 2020. The mobility data of Apple differentiates the driving and walking mobility requests.
Figure 1: Geographical distribution of reported cumulative number of confirmed COVID-19 cases in Indonesia between 8-14 October 2020 [9, 15]

Waze mobility data reports the aggregated and anonymized data of the changes in driven kilometers/miles from the Waze application [18].

We use the daily cases of COVID-19 data in Jakarta (province-level) and Indonesia (country-level) from the official report of the Indonesian Task Force for Rapid Response to COVID-19 [9].

4. Method of Analysis
We employ the cross-correlation technique to estimate the relationship between the human mobility pattern and COVID-19 daily cases in Jakarta, Indonesia. Cross-correlation analysis is one of the most widely used tools for analyzing the multiple time series data. Cross-correlation analysis can be viewed as a rough generalization of the standard linear correlation analysis.

To measure the strength of the correlation between two variables, we calculate the correlation coefficient \((r)\) as follows:

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

where \(r\) is the correlation coefficient of two variables \(x\) and \(y\) of size \(N\) having values of \((x_i, y_i)\) and means of \(\bar{x}\) and \(\bar{y}\) respectively. The coefficient correlation \(r = 1\) indicates that both variables \(x\) and \(y\) are perfectly correlated. If they have a perfect anticorrelation, then \(r = -1\). If they are completely uncorrelated, then \(r = 0\).

Table 1 summarizes the variables used in this paper. The correlation of the mobility patterns is divided into weekdays and weekends.

5. Results and Discussions
In this section, we analyze the correlation between human mobility and the number of COVID-19 cases in Indonesia. Observation data is daily human mobility data reported by Apple, Waze, and Google, and the daily case of COVID-19 in Jakarta and Indonesia. The result of cross-correlation analysis between human mobility pattern and COVID-19 cases in Jakarta (province-level) and Indonesia (country-level) are summarized in Table 2. We will discuss in detail those two analyses. An example of more complete analytical results is described in the Appendix.
Table 1: Summary of Variables Definition

| Variables    | Definition                                      | Source                      |
|--------------|-------------------------------------------------|-----------------------------|
| CovInd_Case  | COVID-19 Cases in Indonesia                     | Task Force for Rapid Response to COVID-19 |
| CovJkt_Case  | COVID-19 Cases in Jakarta                       |                             |
| Ind_D        | Driving mobility in Indonesia                   | Apple                       |
| Jkt_D        | Driving mobility in Jakarta                     |                             |
| Ind_W        | Walking mobility in Indonesia                   |                             |
| Jkt_W        | Walking mobility in Jakarta                     |                             |
| Waze_Ind     | % Change in Waze Driven Miles/KMs in Indonesia  | Waze                        |
| Waze_Jkt     | % Change in Waze Driven Miles/KMs in Jakarta    |                             |
| Ind_RR       | Retail and Recreation percent change from baseline, Indonesia | Google                      |
| Jkt_RR       | Retail and Recreation percent change from baseline, Jakarta |                             |
| Ind_GP       | Grocery and Pharmacy percent change from baseline, Indonesia |                             |
| Jkt_GP       | Grocery and Pharmacy percent change from baseline, Jakarta |                             |
| Ind_Parks    | Parks percent change from baseline, Indonesia   |                             |
| Jkt_Parks    | Parks percent change from baseline, Jakarta     |                             |
| Ind_TS       | Transit Stations percent change from baseline, Indonesia |                             |
| Jkt_TS       | Transit Stations percent change from baseline, Jakarta |                             |
| Ind_WP       | Workplaces percent change from baseline, Indonesia |                             |
| Jkt_WP       | Workplaces percent change from baseline, Jakarta |                             |
| Ind_Res      | Residential percent change from baseline, Indonesia |                             |
| Jkt_Res      | Residential percent change from baseline, Jakarta |                             |

5.1. Mobility Pattern in Indonesia (Country-level) and Its Correlation with COVID-19

On weekdays, the number of COVID-19 cases has a strong and positive correlation with driving mobility (reported by Apple) recorded at 0.5248 as shown in Table 2. The same pattern is seen in pedestrian movement (walking mobility) where the correlation with the COVID-19 case is 0.2878. From other data sources, the movements recorded by the Waze application show that there is a positive correlation between mobility and the COVID-19 case even though the correlation is weak, namely 0.1352. Based on data from the Google Mobility Report, it can be concluded that there is a positive relationship between the number of COVID-19 cases and the movements of Retail and Recreation (0.1724), Grocery and Pharmacy (0.2819), Parks (0.1789), Workplace (0.0365) even though the correlation is weak. On the other hand, there is a negative correlation between COVID-19 cases with Transit Station (-0.0140) and Residential (-0.0011), although the correlation is weak.

On weekends, at the country-level (Indonesia), the number of COVID-19 cases has a strong and positive correlation with the driving mobility reported by Apple, which is 0.5602. The same pattern is seen in pedestrian movements (walking mobility), where the correlation with the COVID-19 case is 0.3668. From other data sources, the movements recorded by the Waze application show that there is a positive correlation between mobility and the COVID-19 case even though the correlation is weak, namely 0.2143. Based on data from the Google Mobility Report, it can be concluded that there is a positive relationship between the number of COVID-19 cases and movements in Retail and Recreation (0.2408), Grocery and Pharmacy (0.3531), Transit Station (0.0707), Parks (0.4030), Workplace (0.2156) although the correlation is weak. On the other hand, there is a negative correlation between COVID-19 and Residential cases,
Table 2: Cross Correlation Analysis between Mobility and COVID-19 Cases

| Mobility               | COVID-19 Cases, Indonesia | COVID-19 Cases, Jakarta |
|------------------------|---------------------------|------------------------|
|                        | Weekdays                  | Weekend                | Weekdays                  | Weekend |
| Driving Mobility       | 0.5248                    | 0.5602                 | 0.5292                    | 0.5609  |
| Walking Mobility       | 0.2878                    | 0.3668                 | 0.5925                    | 0.6233  |
| % Change in Waze Driven Miles/KMs | 0.1352 | 0.2143 | -0.0994 | -0.0606 |
| Retail and Recreation | 0.1724                    | 0.2408                 | 0.0067                    | 0.0570  |
| Grocery and Pharmacy  | 0.2819                    | 0.3531                 | 0.0906                    | 0.1377  |
| Parks                  | 0.1789                    | 0.4030                 | -0.6891                   | -0.5684 |
| Transit Stations       | -0.0140                   | 0.0707                 | -1.1385                   | -0.0541 |
| Workplaces             | 0.0365                    | 0.2156                 | -1.1308                   | -0.0766 |
| Residential            | -0.0011                   | -0.1326                | 0.0603                    | -0.0650 |

although the correlation is weak \((r = -0.1326)\).

5.2. Mobility Pattern in Jakarta (Province-level) and Its Correlation with COVID-19

We are also interested in investigating a more detailed relationship between human mobility and the COVID-19 case in Jakarta (province-level). As also shown in Table 2, on weekdays, the number of COVID-19 cases has a strong and positive correlation with the driving mobility recorded by Apple, which is 0.5292. The same pattern is seen in pedestrian movement (walking mobility) where the correlation with the COVID-19 case is 0.5925. This shows that statistically, the addition of COVID-19 cases in Jakarta has not reduced the movement of vehicles or pedestrians on weekdays.

From other data sources, the movements recorded by the Waze application show that there is a negative correlation between mobility and the COVID-19 case even though the correlation is weak, namely -0.0994. Based on data from the Google Mobility Report, it can be concluded that there is a positive relationship between the number of COVID-19 cases and the movements of Retail and Recreation (0.0067), Grocery and Pharmacy (0.0906), and Residential (0.0603) although the correlation is weak. On the other hand, there is a negative correlation between COVID-19 cases and movements in Parks (-0.6891), Transit Station (-0.1385), and Workplace (-0.1308) in Jakarta on weekdays.

On weekends, the number of COVID-19 cases correlates quite strongly and positively with the driving mobility recorded by Apple, which is 0.5609. The same pattern is seen in pedestrian movement (walking mobility), where the correlation with the COVID-19 case is 0.6233. This shows that statistically, the addition of COVID-19 cases in Jakarta has not reduced the movement of vehicles or pedestrians.

The mobility data recorded by the Waze application show that there is a negative correlation between mobility and the COVID-19 case even though the correlation is weak during the weekend, which is -0.0606. Based on data from the Google Mobility Report, it can be concluded that there is a positive relationship between the number of COVID-19 cases and the movements of Retail and Recreation (0.0570), Grocery and Pharmacy (0.1377) although the correlation is weak. This is presumably a movement to buy basic necessities and medicines. On the other hand, there is a negative correlation between COVID-19 cases and movements at Transit Station (-0.0541), Parks (-0.5684), Workplace (-0.0766), and Residential (-0.0650). This shows that the increase in COVID-19 cases in Jakarta was followed by a decrease in visitors to transit stations, parks, workplaces, and movement in settlements during weekends.
5.3. Lag of Cross-Correlation between Mobility and COVID-19 Cases

The lag cross-correlation shows us the correlation between mobility and cases of COVID-19 at time lag. In the COVID-19 weekdays’ case data, the following synthesis illustrated in Table 3 can be taken into consideration. In general, both at the country-level and the province-level (Jakarta), mobility on the \( t \)-day correlates with an increase or decrease in COVID-19 cases in a week (7 days) and two weeks (13 days and 14 days) before or after. This is in line with the incubation pattern of the COVID-19 virus, which is 7-14 days.

Table 3: Lag of Cross Correlation between Mobility and COVID-19 Cases

| Mobility                  | COVID-19 Cases, Indonesia | COVID-19 Cases, Jakarta |
|---------------------------|---------------------------|-------------------------|
|                           | Lag of 2 Highest Cross-Corr. | Cross-Corr. Value | Lag of 2 Highest Cross-Corr. | Cross-Corr. Value |
| Driving Mobility          | 7\(^{th}\) | 0.5417 | 7\(^{th}\) | 0.5839 |
|                           | 14\(^{th}\) | 0.5542 | 14\(^{th}\) | 0.6423 |
| Walking Mobility          | 7\(^{th}\) | 0.3711 | 7\(^{th}\) | 0.6232 |
|                           | 14\(^{th}\) | 0.4411 | 14\(^{th}\) | 0.6648 |
| % Change in Waze Driven Miles/KMs | 13\(^{th}\) | 0.2561 | 13\(^{th}\) | 0.1984 |
|                           | 14\(^{th}\) | 0.3447 | 14\(^{th}\) | 0.2732 |
| Retail and Recreation     | 13\(^{th}\) | 0.2659 | 13\(^{th}\) | 0.2415 |
|                           | 14\(^{th}\) | 0.3565 | 14\(^{th}\) | 0.332 |
| Grocery and Pharmacy      | 7\(^{th}\) | 0.334 | 13\(^{th}\) | 0.2682 |
|                           | 14\(^{th}\) | 0.3721 | 14\(^{th}\) | 0.364 |
| Parks                     | 7\(^{th}\) | 0.2579 | -7\(^{th}\) | -0.7046 |
|                           | 14\(^{th}\) | 0.3497 | -14\(^{th}\) | -0.7068 |
| Transit Stations          | 13\(^{th}\) | 0.1813 | -13\(^{th}\) | -0.2119 |
|                           | 14\(^{th}\) | 0.2491 | -14\(^{th}\) | -0.2879 |
| Workplaces                | 13\(^{th}\) | 0.1828 | -7\(^{th}\) | -0.2009 |
|                           | 14\(^{th}\) | 0.2574 | -14\(^{th}\) | -0.2682 |
| Residential               | 13\(^{th}\) | -0.1681 | 13\(^{th}\) | -0.1891 |
|                           | 14\(^{th}\) | -0.2472 | 14\(^{th}\) | -0.2791 |

When viewed at the country-level, in almost all types of mobility, the lag is positive, except for residential movement. This positive correlation shows that increased mobility will be followed by an increase in COVID-19 cases in the next 7\(^{th}\), 13\(^{th}\), and 14\(^{th}\) periods. The lag correlation in the residential movement which is negative is indicated because the movement is a movement activity with a low risk of spreading COVID-19.

From the province-level (Jakarta) point of view, at Driving, Walking, Retail and Recreation, and Grocery and Pharmacy there is a positive correlation lag. The highest correlation lag also occurred in a week (7 days) and two weeks (13 days and 14 days). This positive correlation shows that increased mobility will be followed by an increase in COVID-19 cases in the next 7\(^{th}\), 13\(^{th}\), and 14\(^{th}\) days. This movement is difficult to avoid, especially the needs of the population to buy food and medicine. Different patterns are found in Parks, Transit Stations, Workplaces, and Residential. A negative correlation value shows that mobility is accompanied by a decrease in COVID-19 cases in Jakarta on the next 7\(^{th}\), 13\(^{th}\), and 14\(^{th}\) days. This shows that the large-scale social restrictions carried out by the government are considered quite successful in reducing the spread of COVID-19. The closure of public facilities such as parks, as well as restrictions on working hours in most offices in Jakarta has resulted in the transit stations and workplace not being overcrowded, thereby reducing the risk of spreading COVID-19. Statistically, the policy of
large scale social restrictions in Jakarta has proven effective in controlling the rate of COVID-19 cases.

6. Conclusions
In this paper, we investigate the correlation between population mobility patterns and the transmission of COVID-19 in Jakarta, Indonesia. To address this issue, we utilize the publicly accessible mobility data of Google, Waze, and Apple. Our analysis revealed that the COVID-19 case daily growth rates are correlated with the human mobility patterns of driving and walking movements on both weekends and weekdays time in Jakarta, Indonesia.

The result of our analysis confirms an essential role of the travel restriction and social distancing among the most efficient mitigation policies to scale-down the pandemic in Indonesia. Social distancing still remains the primary measure until any proven vaccines are widely accessible. Our findings in this study could assist the governmental policy making in the near future.

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## Appendix

1: Cross-Correlation of Mobility (Weekdays) and COVID-19 Cases in Indonesia

### (a) Driving Mobility, lags(14)

| LAG | CORR  |
|-----|-------|
| -14 | 0.2773 |
| -13 | 0.2349 |
| -12 | 0.1807 |
| -11 | 0.1830 |
| -10 | 0.2245 |
| -9  | 0.2295 |
| -8  | 0.3043 |
| -7  | 0.4295 |
| -6  | 0.3557 |
| -5  | 0.2773 |
| -4  | 0.2654 |
| -3  | 0.3400 |
| -2  | 0.2850 |
| -1  | 0.3707 |
| 0   | 0.5248 |
| 1   | 0.4309 |
| 2   | 0.3235 |
| 3   | 0.2260 |
| 4   | 0.3288 |
| 5   | 0.2972 |
| 6   | 0.3977 |
| 7   | 0.5417 |
| 8   | 0.4428 |
| 9   | 0.3401 |
| 10  | 0.3559 |
| 11  | 0.3379 |
| 12  | 0.3108 |
| 13  | 0.4155 |
| 14  | 0.3542 |

### (b) Walking Mobility, lags(14)

| LAG | CORR  |
|-----|-------|
| -14 | 0.1934 |
| -13 | 0.0958 |
| -12 | 0.0853 |
| -11 | 0.0927 |
| -10 | 0.1908 |
| -9  | 0.1916 |
| -8  | 0.1433 |
| -7  | 0.2155 |
| -6  | 0.3854 |
| -5  | 0.3532 |
| -4  | 0.1527 |
| -3  | 0.1571 |
| -2  | 0.1444 |
| -1  | 0.1994 |
| 0   | 0.2078 |
| 1   | 0.2432 |
| 2   | 0.1997 |
| 3   | 0.3796 |
| 4   | 0.2094 |
| 5   | 0.1997 |
| 6   | 0.2710 |
| 7   | 0.3711 |
| 8   | 0.3958 |
| 9   | 0.2305 |
| 10  | 0.3447 |
| 11  | 0.2958 |
| 12  | 0.2472 |
| 13  | 0.3332 |
| 14  | 0.4411 |

### (c) Mobility in Retail and Recreation, lags(14)

| LAG | CORR  |
|-----|-------|
| -14 | -0.8138 |
| -13 | -0.8946 |
| -12 | -0.8152 |
| -11 | -0.8107 |
| -10 | -0.8324 |
| -9  | -0.8437 |
| -8  | -0.8650 |
| -7  | -0.8953 |
| -6  | -0.8907 |
| -5  | -0.8750 |
| -4  | -0.8774 |
| -3  | -0.8803 |
| -2  | -0.8921 |
| -1  | -0.8123 |
| 0   | 0.2139 |
| 1   | 0.2293 |
| 2   | 0.1774 |
| 3   | 0.1177 |
| 4   | 0.1269 |
| 5   | 0.1420 |
| 6   | 0.1451 |
| 7   | 0.1660 |
| 8   | 0.2644 |
| 9   | 0.2186 |
| 10  | 0.1709 |
| 11  | 0.1643 |
| 12  | 0.2014 |
| 13  | 0.1900 |
| 14  | 0.2698 |

### (d) Mobility in Grocery and Pharmacy, lags(14)

| LAG | CORR  |
|-----|-------|
| -14 | -0.1765 |
| -13 | -0.1553 |
| -12 | -0.1702 |
| -11 | -0.1120 |
| -10 | -0.1300 |
| -9  | -0.1423 |
| -8  | -0.1924 |
| -7  | -0.2911 |
| -6  | -0.2148 |
| -5  | -0.1647 |
| -4  | -0.1546 |
| -3  | -0.1646 |
| -2  | -0.1639 |
| -1  | -0.2150 |
| 0   | 0.2319 |
| 1   | 0.2253 |
| 2   | 0.1754 |
| 3   | 0.1859 |
| 4   | 0.2845 |
| 5   | 0.1902 |
| 6   | 0.2551 |
| 7   | 0.3340 |
| 8   | 0.2600 |
| 9   | 0.1900 |
| 10  | 0.2155 |
| 11  | 0.2376 |
| 12  | 0.2248 |
| 13  | 0.2610 |
| 14  | 0.5721 |
| LAG | CORR | (cross-correlation) |
|-----|------|---------------------|
| -14 | 0.0372 |                     |
| -13 | 0.0314 |                     |
| -12 | 0.0236 |                     |
| -11 | 0.0188 |                     |
| -10 | 0.0143 |                     |
| -9  | 0.0095 |                     |
| -8  | 0.0057 |                     |
| -7  | 0.0032 |                     |
| -6  | 0.0016 |                     |
| -5  | 0.0008 |                     |
| -4  | 0.0004 |                     |
| -3  | 0.0002 |                     |
| -2  | 0.0001 |                     |
| -1  | -0.0001|                     |
| 0   | -0.0003|                     |
| 1   | -0.0005|                     |
| 2   | -0.0008|                     |
| 3   | -0.0011|                     |
| 4   | -0.0014|                     |
| 5   | -0.0016|                     |
| 6   | -0.0018|                     |
| 7   | -0.0020|                     |
| 8   | -0.0022|                     |
| 9   | -0.0024|                     |
| 10  | -0.0026|                     |
| 11  | -0.0028|                     |
| 12  | -0.0030|                     |
| 13  | -0.0032|                     |
| 14  | -0.0034|                     |

(a) Mobility in Parks, lags(14)

| LAG | CORR | (cross-correlation) |
|-----|------|---------------------|
| -14 | -0.0922|                     |
| -13 | -0.0447|                     |
| -12 | -0.0159|                     |
| -11 | -0.0066|                     |
| -10 | -0.0008|                     |
| -9  | -0.0009|                     |
| -8  | -0.0009|                     |
| -7  | -0.0008|                     |
| -6  | -0.0007|                     |
| -5  | -0.0006|                     |
| -4  | -0.0005|                     |
| -3  | -0.0004|                     |
| -2  | -0.0003|                     |
| -1  | -0.0002|                     |
| 0   | -0.0001|                     |
| 1   | -0.0000|                     |
| 2   | -0.0000|                     |
| 3   | -0.0000|                     |
| 4   | -0.0000|                     |
| 5   | -0.0000|                     |
| 6   | -0.0000|                     |
| 7   | -0.0000|                     |
| 8   | -0.0000|                     |
| 9   | -0.0000|                     |
| 10  | -0.0000|                     |
| 11  | -0.0000|                     |
| 12  | -0.0000|                     |
| 13  | -0.0000|                     |
| 14  | -0.0000|                     |

(b) Mobility in Transit Stations, lags(14)

| LAG | CORR | (cross-correlation) |
|-----|------|---------------------|
| -14 | -0.1050|                     |
| -13 | -0.1141|                     |
| -12 | -0.0756|                     |
| -11 | -0.0436|                     |
| -10 | -0.0710|                     |
| -9  | -0.0314|                     |
| -8  | -0.0738|                     |
| -7  | -0.0779|                     |
| -6  | -0.0640|                     |
| -5  | -0.0251|                     |
| -4  | -0.0253|                     |
| -3  | -0.0264|                     |
| -2  | -0.0230|                     |
| -1  | -0.0223|                     |
| 0   | -0.0340|                     |
| 1   | 0.0070 |                     |
| 2   | 0.0185 |                     |
| 3   | 0.0219 |                     |
| 4   | 0.0418 |                     |
| 5   | 0.0557 |                     |
| 6   | 0.0805 |                     |
| 7   | 0.1200 |                     |
| 8   | 0.1954 |                     |
| 9   | 0.0088 |                     |
| 10  | 0.1959 |                     |
| 11  | 0.1247 |                     |
| 12  | 0.1326 |                     |
| 13  | 0.1813 |                     |
| 14  | 0.2401 |                     |

(c) Mobility in Workplaces, lags(14)

| LAG | CORR | (cross-correlation) |
|-----|------|---------------------|
| -14 | 0.0240|                     |
| -13 | 0.0201|                     |
| -12 | 0.0095|                     |
| -11 | 0.0057|                     |
| -10 | 0.0032|                     |
| -9  | 0.0016|                     |
| -8  | 0.0008|                     |
| -7  | 0.0004|                     |
| -6  | 0.0002|                     |
| -5  | 0.0001|                     |
| -4  | 0.0000|                     |
| -3  | 0.0000|                     |
| -2  | 0.0000|                     |
| -1  | 0.0000|                     |
| 0   | 0.0000|                     |
| 1   | 0.0000|                     |
| 2   | 0.0000|                     |
| 3   | 0.0000|                     |
| 4   | 0.0000|                     |
| 5   | 0.0000|                     |
| 6   | 0.0000|                     |
| 7   | 0.0000|                     |
| 8   | 0.0000|                     |
| 9   | 0.0000|                     |
| 10  | 0.0000|                     |
| 11  | 0.0000|                     |
| 12  | 0.0000|                     |
| 13  | 0.0000|                     |
| 14  | 0.0000|                     |

(d) Mobility in Residential, lags(14)
2: Cross-Correlation of Mobility (Weekdays) and COVID-19 Cases in Jakarta

(a) Driving Mobility, lags(14)

| LAG | CORR [Cross-correlation] |
|-----|-------------------------|
| -14 | 0.2554                  |
| -13 | 0.2152                  |
| -12 | 0.1869                  |
| -11 | 0.1609                  |
| -10 | 0.2129                  |
| -9  | 0.2159                  |
| -8  | 0.2808                  |
| -7  | 0.4220                  |
| -6  | 0.3400                  |
| -5  | 0.2653                  |
| -4  | 0.2600                  |
| -3  | 0.3822                  |
| -2  | 0.2853                  |
| -1  | 0.2628                  |
| 0   | 0.5292                  |
| 1   | 0.4343                  |
| 2   | 0.3326                  |
| 3   | 0.3373                  |
| 4   | 0.3435                  |
| 5   | 0.3140                  |
| 6   | 0.4260                  |
| 7   | 0.5639                  |
| 8   | 0.4789                  |
| 9   | 0.3707                  |
| 10  | 0.3778                  |
| 11  | 0.3621                  |
| 12  | 0.3518                  |
| 13  | 0.4755                  |
| 14  | 0.6423                  |

(b) Walking Mobility, lags(14)

| LAG | CORR [Cross-correlation] |
|-----|-------------------------|
| -14 | 0.3202                  |
| -13 | 0.2700                  |
| -12 | 0.2129                  |
| -11 | 0.2238                  |
| -10 | 0.2478                  |
| -9  | 0.2543                  |
| -8  | 0.3403                  |
| -7  | 0.4874                  |
| -6  | 0.4846                  |
| -5  | 0.3158                  |
| -4  | 0.3226                  |
| -3  | 0.3379                  |
| -2  | 0.3184                  |
| -1  | 0.4274                  |
| 0   | 0.5925                  |
| 1   | 0.4699                  |
| 2   | 0.3749                  |
| 3   | 0.3716                  |
| 4   | 0.3774                  |
| 5   | 0.3351                  |
| 6   | 0.4544                  |
| 7   | 0.4322                  |
| 8   | 0.5100                  |
| 9   | 0.3914                  |
| 10  | 0.4096                  |
| 11  | 0.4050                  |
| 12  | 0.3659                  |
| 13  | 0.4065                  |
| 14  | 0.6648                  |

(c) Mobility in Retail and Recreation, lags(14)

| LAG | CORR [Cross-correlation] |
|-----|-------------------------|
| -14 | -0.1600                  |
| -13 | -0.1578                  |
| -12 | -0.0093                  |
| -11 | -0.0848                  |
| -10 | -0.0786                  |
| -9  | -0.0674                  |
| -8  | -0.0557                  |
| -7  | -0.0595                  |
| -6  | -0.0228                  |
| -5  | -0.0205                  |
| -4  | -0.0251                  |
| -3  | -0.0512                  |
| -2  | -0.0212                  |
| -1  | 0.0807                   |
| 0   | 0.8249                   |
| 1   | 0.8249                   |
| 2   | 0.9459                   |
| 3   | 0.8648                   |
| 4   | 0.7966                   |
| 5   | 0.1145                   |
| 6   | 0.1691                   |
| 7   | 0.1440                   |
| 8   | 0.1238                   |
| 9   | 0.1457                   |
| 10  | 0.1652                   |
| 11  | 0.1775                   |
| 12  | 0.2415                   |
| 13  | 0.3320                   |

(d) Mobility in Grocery and Pharmacy, lags(14)

| LAG | CORR [Cross-correlation] |
|-----|-------------------------|
| -14 | -0.0593                  |
| -13 | -0.0251                  |
| -12 | 0.0882                   |
| -11 | 0.0916                   |
| -10 | 0.0115                   |
| -9  | -0.0174                  |
| -8  | -0.0011                  |
| -7  | 0.0299                   |
| -6  | 0.0377                   |
| -5  | 0.0513                   |
| -4  | 0.0516                   |
| -3  | 0.0278                   |
| -2  | 0.0213                   |
| -1  | 0.0486                   |
| 0   | 0.0806                   |
| 1   | 0.0706                   |
| 2   | 0.0640                   |
| 3   | 0.1393                   |
| 4   | 0.1259                   |
| 5   | 0.1207                   |
| 6   | 0.1753                   |
| 7   | 0.2457                   |
| 8   | 0.1801                   |
| 9   | 0.1599                   |
| 10  | 0.1373                   |
| 11  | 0.2854                   |
| 12  | 0.2859                   |
| 13  | 0.2162                   |
| 14  | 0.2648                   |
(a) Mobility in Parks, lags(14)  

| LAG | CORR | -1 | 0 | 1 |
|-----|------|----|---|---|
| -14 | ~-0.7868 |    |   |   |
| -13 | ~-0.5543 |    |   |   |
| -12 | ~-0.4138 |    |   |   |
| -11 | ~-0.4463 |    |   |   |
| -10 | ~-0.4301 |    |   |   |
| -9  | ~-0.4389 |    |   |   |
| -8  | ~-0.5550 |    |   |   |
| -7  | ~0.7246  |    |   |   |
| -6  | ~0.5521  |    |   |   |
| -5  | ~0.4804  |    |   |   |
| -4  | ~0.4310  |    |   |   |
| -3  | ~0.4338  |    |   |   |
| -2  | ~0.4264  |    |   |   |
| -1  | ~0.5559  |    |   |   |
| 0   | ~0.5481  |    |   |   |
| 1   | ~0.5315  |    |   |   |
| 2   | ~0.3956  |    |   |   |
| 3   | ~0.3736  |    |   |   |
| 4   | ~0.3471  |    |   |   |
| 5   | ~0.3892  |    |   |   |
| 6   | ~0.3989  |    |   |   |
| 7   | ~0.4462  |    |   |   |
| 8   | ~0.3770  |    |   |   |
| 9   | ~0.2730  |    |   |   |
| 10  | ~0.2464  |    |   |   |
| 11  | ~0.2156  |    |   |   |
| 12  | ~0.1678  |    |   |   |
| 13  | ~0.2415  |    |   |   |
| 14  | ~0.2844  |    |   |   |

(b) Mobility in Transit Stations, lags(14)  

| LAG | CORR | -1 | 0 | 1 |
|-----|------|----|---|---|
| -14 | ~0.2879 |    |   |   |
| -13 | ~0.2139 |    |   |   |
| -12 | ~0.1403 |    |   |   |
| -11 | ~0.1502 |    |   |   |
| -10 | ~0.3510 |    |   |   |
| -9  | ~0.1443 |    |   |   |
| -8  | ~0.3640 |    |   |   |
| -7  | ~0.2109 |    |   |   |
| -6  | ~0.1505 |    |   |   |
| -5  | ~0.1619 |    |   |   |
| -4  | ~0.1319 |    |   |   |
| -3  | ~0.1871 |    |   |   |
| -2  | ~0.1835 |    |   |   |
| -1  | ~0.1283 |    |   |   |
| 0   | ~0.1365 |    |   |   |
| 1   | ~0.0927 |    |   |   |
| 2   | ~0.0571 |    |   |   |
| 3   | ~0.0416 |    |   |   |
| 4   | ~0.0140 |    |   |   |
| 5   | ~0.0804 |    |   |   |
| 6   | ~0.0231 |    |   |   |
| 7   | ~0.0527 |    |   |   |
| 8   | ~0.0508 |    |   |   |
| 9   | ~0.0502 |    |   |   |
| 10  | ~0.0775 |    |   |   |
| 11  | ~0.1842 |    |   |   |
| 12  | ~0.1244 |    |   |   |
| 13  | ~0.1753 |    |   |   |
| 14  | ~0.2450 |    |   |   |

(c) Mobility in Workplaces, lags(14)  

| LAG | CORR | -1 | 0 | 1 |
|-----|------|----|---|---|
| -14 | ~0.2662 |    |   |   |
| -13 | ~0.1079 |    |   |   |
| -12 | ~0.1201 |    |   |   |
| -11 | ~0.3558 |    |   |   |
| -10 | ~0.1599 |    |   |   |
| -9  | ~0.1365 |    |   |   |
| -8  | ~0.1814 |    |   |   |
| -7  | ~0.2809 |    |   |   |
| -6  | ~0.1230 |    |   |   |
| -5  | ~0.0846 |    |   |   |
| -4  | ~0.1123 |    |   |   |
| -3  | ~0.1000 |    |   |   |
| -2  | ~0.1028 |    |   |   |
| -1  | ~0.1279 |    |   |   |
| 0   | ~0.1268 |    |   |   |
| 1   | ~0.0782 |    |   |   |
| 2   | ~0.2465 |    |   |   |
| 3   | ~0.1045 |    |   |   |
| 4   | ~0.7230 |    |   |   |
| 5   | ~0.0521 |    |   |   |
| 6   | ~0.0236 |    |   |   |
| 7   | ~0.0236 |    |   |   |
| 8   | ~0.0493 |    |   |   |
| 9   | ~0.0569 |    |   |   |
| 10  | ~0.0030 |    |   |   |
| 11  | ~0.0037 |    |   |   |
| 12  | ~0.0539 |    |   |   |
| 13  | ~0.0636 |    |   |   |
| 14  | ~0.1915 |    |   |   |

(d) Mobility in Residential, lags(14)  

| LAG | CORR | -1 | 0 | 1 |
|-----|------|----|---|---|
| -14 | ~0.2662 |    |   |   |
| -13 | ~0.2670 |    |   |   |
| -12 | ~0.1575 |    |   |   |
| -11 | ~0.1200 |    |   |   |
| -10 | ~0.1082 |    |   |   |
| -9  | ~0.0936 |    |   |   |
| -8  | ~0.1211 |    |   |   |
| -7  | ~0.1349 |    |   |   |
| -6  | ~0.0900 |    |   |   |
| -5  | ~0.0547 |    |   |   |
| -4  | ~0.0650 |    |   |   |
| -3  | ~0.0635 |    |   |   |
| -2  | ~0.0934 |    |   |   |
| -1  | ~0.0953 |    |   |   |
| 0   | ~0.0603 |    |   |   |
| 1   | ~0.0319 |    |   |   |
| 2   | ~0.0278 |    |   |   |
| 3   | ~0.0040 |    |   |   |
| 4   | ~0.0236 |    |   |   |
| 5   | ~0.0454 |    |   |   |
| 6   | ~0.0018 |    |   |   |
| 7   | ~0.0018 |    |   |   |
| 8   | ~0.0115 |    |   |   |
| 9   | ~0.0115 |    |   |   |
| 10  | ~0.0139 |    |   |   |
| 11  | ~0.1351 |    |   |   |
| 12  | ~0.1401 |    |   |   |
| 13  | ~0.1915 |    |   |   |
| 14  | ~0.2701 |    |   |   |
3: Cross-Correlation of Mobility (Weekend) and COVID-19 Cases in Indonesia

| LAG | CORR  | [Cross-correlation] | LAG | CORR  | [Cross-correlation] |
|-----|-------|---------------------|-----|-------|---------------------|
| -7  | 0.4540|                     | -7  | 0.2008|                     |
| -6  | 0.1737|                     | -5  | 0.8916|                     |
| -5  | 0.8000|                     | -5  | 0.8000|                     |
| -4  | 0.8000|                     | -4  | 0.8000|                     |
| -3  | 0.8000|                     | -3  | 0.8000|                     |
| -2  | 0.8000|                     | -2  | 0.8000|                     |
| -1  | 0.2512|                     | -1  | 0.2455|                     |
| 0   | 0.5602|                     | 0   | 0.3698|                     |
| 1   | 0.2444|                     | 1   | 0.1692|                     |
| 2   | 0.0000|                     | 2   | 0.0000|                     |
| 3   | 0.0000|                     | 3   | 0.0000|                     |
| 4   | 0.0000|                     | 4   | 0.0000|                     |
| 5   | 0.0000|                     | 5   | 0.0000|                     |
| 6   | 0.2954|                     | 6   | 0.2076|                     |
| 7   | 0.5731|                     | 7   | 0.4327|                     |

| LAG | CORR  | [Cross-correlation] | LAG | CORR  | [Cross-correlation] |
|-----|-------|---------------------|-----|-------|---------------------|
| -7  | 0.1626|                     | -7  | 0.3074|                     |
| -6  | 0.0666|                     | -5  | 0.1450|                     |
| -5  | 0.0000|                     | -5  | 0.0000|                     |
| -4  | 0.0000|                     | -4  | 0.0000|                     |
| -3  | 0.0000|                     | -3  | 0.0000|                     |
| -2  | 0.0000|                     | -2  | 0.0000|                     |
| -1  | 0.1346|                     | -1  | 0.1301|                     |
| 0   | 0.2408|                     | 0   | 0.2531|                     |
| 1   | 0.1572|                     | 1   | 0.2125|                     |
| 2   | 0.0000|                     | 2   | 0.0000|                     |
| 3   | 0.0000|                     | 3   | 0.0000|                     |
| 4   | 0.0000|                     | 4   | 0.0000|                     |
| 5   | 0.0000|                     | 5   | 0.0000|                     |
| 6   | 0.1155|                     | 6   | 0.1442|                     |
| 7   | 0.3206|                     | 7   | 0.3862|                     |
4: Cross-Correlation of Mobility (Weekend) and COVID-19 Cases in Jakarta

(a) Driving Mobility, lags(7)

| LAG | CORR | [Cross-correlation] |
|-----|------|----------------------|
| -7  | 0.4366 |                      |
| -6  | 0.1679 |                      |
| -5  | 0.0000 |                      |
| -4  | 0.0000 |                      |
| -3  | 0.0000 |                      |
| -2  | 0.0000 |                      |
| -1  | 0.3452 |                      |
| 0   | 0.5609 |                      |
| 1   | 0.2540 |                      |
| 2   | 0.0000 |                      |
| 3   | 0.0000 |                      |
| 4   | 0.0000 |                      |
| 5   | 0.0000 |                      |
| 6   | 0.3973 |                      |
| 7   | 0.6196 |                      |

(b) Walking Mobility, lags(7)

| LAG | CORR | [Cross-correlation] |
|-----|------|----------------------|
| -7  | 0.5089 |                      |
| -6  | 0.2810 |                      |
| -5  | 0.0000 |                      |
| -4  | 0.0000 |                      |
| -3  | 0.0000 |                      |
| -2  | 0.0000 |                      |
| -1  | 0.3531 |                      |
| 0   | 0.5233 |                      |
| 1   | 0.2713 |                      |
| 2   | 0.0000 |                      |
| 3   | 0.0000 |                      |
| 4   | 0.0000 |                      |
| 5   | 0.0000 |                      |
| 6   | 0.3390 |                      |
| 7   | 0.6580 |                      |

(c) Mobility in Retail and Recreation, lags(7)

| LAG | CORR | [Cross-correlation] |
|-----|------|----------------------|
| -7  | -0.0353 |                     |
| -6  | -0.0581 |                     |
| -5  | 0.0000  |                     |
| -4  | 0.0000  |                     |
| -3  | 0.0000  |                     |
| -2  | 0.0000  |                     |
| -1  | 0.0501  |                     |
| 0   | 0.0570  |                     |
| 1   | 0.0750  |                     |
| 2   | 0.0000  |                     |
| 3   | 0.0000  |                     |
| 4   | 0.0000  |                     |
| 5   | 0.0000  |                     |
| 6   | 0.0560  |                     |
| 7   | 0.2188  |                     |

(d) Mobility in Grocery and Parks, lags(7)

| LAG | CORR | [Cross-correlation] |
|-----|------|----------------------|
| -7  | 0.0642 |                     |
| -6  | 0.0921 |                     |
| -5  | 0.0000 |                     |
| -4  | 0.0000 |                     |
| -3  | 0.0000 |                     |
| -2  | 0.0000 |                     |
| -1  | 0.0927 |                     |
| 0   | 0.1377 |                     |
| 1   | 0.1091 |                     |
| 2   | 0.0000 |                     |
| 3   | 0.0000 |                     |
| 4   | 0.0000 |                     |
| 5   | 0.0000 |                     |
| 6   | 0.0785 |                     |
| 7   | 0.2695 |                     |