EVALUATING COVID-19 MOVEMENT RESTRICTIONS: A FINNISH CASE STUDY

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A case study has been conducted to substantiate the effects of the lockdown imposed on the Uusimaa area in Finland. In particular, the case study aims to find out if the Uusimaa lockdown has mitigated the spread of the coronavirus from Uusimaa to other parts of Finland. The study shows that after the lockdown was imposed, it took approximately two weeks before the daily count of new COVID-19 cases outside the Uusimaa area reached its peak and started to decrease. The phenomenon aligns with the findings of relevant studies that a peak in the curve of diagnosed cases of infection occurs 14 to 18 days from lockdown. It also emerges that the lifting of the lockdown on Uusimaa caused immediate outflowing mobility but did not result in an increased number of new cases in other parts of Finland.

Keywords: Covid-19, movement restrictions, non-pharmaceutical interventions, visual analytics, machine learning

University of Maribor Press

DOI https://doi.org/10.18690/um.fov.4.2024.33
ISBN 978-961-286-871-0

1 Introduction

In early 2020, the world faced the COVID-19 pandemic caused by the SARS-CoV-2 virus. This unprecedented health crisis prompted nations to impose travel restrictions and other public health measures, including mandatory mask-wearing, the closure of non-essential businesses, and restrictions on public gatherings. Alongside these measures, many countries implemented national or regional restrictions on movement. These restrictions raised concerns about their impact on personal freedoms and the necessity for substantial research to assess their effectiveness in reducing the transmission of COVID-19. This research is crucial given that movement-based disease control represents a relatively new approach in modern public health strategies.

In Finland, during the early stage of the pandemic in 2020, a movement restriction in the form of a regional lockdown was introduced. Finland's most populated region Uusimaa was put under a three-week lockdown from March 28 to April 15. Such a radical measure raises the question of its efficacy, what was the effect of this lockdown in mitigating the spread of the virus?

Our research examines the extent to which the Uusimaa region lockdown was effective in attenuating the propagation of the coronavirus from the Uusimaa region to *other* regions within Finland. This study seeks to offer critical understanding that may inform responses to future infectious disease outbreaks, as no similar research on this specific subject has been conducted in Finland, making this study a pioneering contribution to the field. We test the hypothesis that mobility is linked to the number of new COVID-19 cases. The main research question is:

- Is there a relationship between change in mobility and the number of new cases?

2 Literature review

Direct evidence of the effectiveness of movement restrictions in mitigating the spread of COVID-19 in Finland is limited. Consequently, we commence with an analysis of outcomes from nations that have enforced comparable non-pharmaceutical interventions (NPIs). The scope of this literature review is confined to examining the impact of NPIs instituted in the initial phase of the pandemic, aligning with the temporal context of our case study in Finland.

2.1 Global Perspective on NPI Effectiveness

We first examine a global perspective on the implementation and outcomes of various governmental interventions. Haug et al. (2020) applied four different regression techniques (namely case-control analysis, step function Lasso regression, random forest regression, and transformers modeling) to quantify the impact of 46 NPIs implemented in the first infection wave in 79 territories (Desvars-Larrive et al., 2020). To be more specific, they investigated their effects on the reduction in the effective reproduction number, R_t, which is an essential epidemiological quantity that represents the average number of infections generated at time t by each infected case throughout their infection. The results suggested that no individual NPI had been successful at reducing R_t to values below 1. Nevertheless, by combining the results yielded by the above methods, a set of six NPIs which all four methods show significant results for was identified. Small gathering cancellations (estimated ΔR_t ranging from -0.22 to -0.35), the closure of educational institutions (estimated ΔR_t ranging from -0.15 to -0.21), and border restrictions (estimated ΔR_t ranging from -0.057 to -0.23) were the three most effective NPIs, while cordon sanitaire was found to have a significantly positive effect on reducing ΔR_t (estimated ΔR_t being around -0.09) by only random forest regression and transformers modeling.

Hsiang et al. (2020) investigated the direct health benefits of NPIs, which were deployed by the governments of China, South Korea, Italy, Iran, France, and the United States. The dataset commences with the first travel ban imposed in Wuhan, China, on January 23, 2020, and encompasses all subsequent restrictive anti-contagion policies adopted in the aforementioned countries up to April 6, 2020, together with the corresponding daily infection rates. They applied panel regression models to estimate how the daily growth rate of infections changed over time within a location when different combinations of NPIs were deployed. They estimated that, in the absence of NPIs, early infection rates of COVID-19 would have grown 43% per day on average across the subject countries, which corresponds to a staggering doubling time of two days. However, once all anti-contagion policies were implemented, their estimated combined effect would reduce the daily growth rate of infections by a substantial and statistically significant amount. Among all the NPIs, travel bans, and social distancing were found to be the most effective, which were expected to lower the daily growth rate by 28% and 22%, respectively.

Flaxman et al. (2020) analyzed the impact of five types of governmental interventions across 11 European countries for the period from February to May 2020, and they were also interested in assessing their effectiveness in reducing the reproduction number R_t. Unlike the work mentioned above, a Bayesian inference framework, which involves back-calculating from observed deaths to infer the total population infected and the subsequent impact of interventions, was utilized in this study. It concluded that interventions were effective in reducing the reproduction number R_t below 1 in all countries considered, hence containing the epidemic. Among the five governmental interventions included in this study, only the effectiveness of lockdown was identifiable, and it was estimated to have led to a remarkable reduction of 81% in R_t if the model was fitted to the pooled data from all 11 European countries.

In conducting our literature review, we also endeavored to incorporate research focused on the Nordic region due to their shared geographical, political, and social characteristics. Our emphasis was primarily on Finland, Norway, and Denmark, which was motivated by these countries' implementation of comparatively stringent restrictions on population mobility. Banholzer et al. (2021) proposed a model that linked two unobserved quantities (i.e., the daily number of contagious subjects and the daily number of new infections) to an observed quantity (i.e., the number of reported new cases). They assessed the impact of seven NPIs on curbing the number of new infections, deduced from the number of reported new cases through a semi-mechanistic Bayesian hierarchical model. This research spanned 20 nations, including Finland, Norway, and Denmark. The findings revealed that prohibitions on large gatherings were the most effective, associated with a 37% reduction in new infections. This was followed by venue closures at 18% and school closures at 17%. Despite these findings, the study did not individually exhibit the effects of these interventions in any of these countries.

As we progress, it is crucial to delve into the impact of NPIs on an individual country level. We first turn our attention to China, the epicenter where the outbreak began, to understand the genesis of the containment strategies that would later sweep across the globe. Additionally, a review of Italy's experience is imperative as it represents the first European nation to confront the pandemic head-on with extensive lockdown measures. Incorporating studies specifically from the Nordic countries would have added valuable insights; however, our search did not uncover any research exclusively focused on these nations.

Utilizing real-time human mobility data from Wuhan and epidemiological data from other provinces, including travel histories, Kraemer et al. (2020) aimed to elucidate whether epidemics outside of Wuhan could be predicted by the volume of human movement out of Wuhan and to evaluate the efficacy of the cordon sanitaire. For these purposes, they built three generalized linear models (namely Poisson regression, negative Binomial, and log-linear regression) of daily case counts. The models suggested that the volume of human movement out of Wuhan alone was well predictive of the magnitude of the early epidemic outside of Wuhan. However, the correlation decreased after February 1, 2020, corresponding to one mean plus one standard deviation of the incubation period after the interventions were implemented.

Quilty et al. (2020) analyzed the impact of Wuhan's travel restrictions on slowing the virus's spread. They revealed that the cordon sanitaire, which was put into place on January 23, 2020, significantly reduced Wuhan's outflow by 92.7%. Despite this, local transmissions in major cities like Beijing, Chongqing, Hangzhou, and Shenzhen likely began well before the restrictions, diminishing the measure's overall effectiveness in altering the spread of the infection. They also modeled a scenario in which no cordon sanitaire was implemented. The simulation suggested that the cordon sanitaire's influence was negligible in these larger cities due to pre-existing high infection rates. However, Quilty et al. argued that the cordon sanitaire demonstrated a more pronounced effect in smaller cities. They concluded by suggesting other stringent NPIs had a greater effect on the development of COVID-19 than travel restrictions (Quilty et al., 2020).

Santamaria et al. (2020) conducted a study about movement restrictions and the effect of COVID-19 in Europe. In the study, they developed a mobility indicator to evaluate the effects of lockdowns on movement across European countries, focusing on Italy's response to COVID-19. Utilizing anonymized mobile data, the researchers crafted an origin-destination matrix to track mobility trends. Their analysis revealed significant mobility reductions in countries with stringent lockdowns, such as Spain, Italy, and France, compared to those with milder restrictions. The study also examined the relationship between mobility and the effective reproduction number R_t in Italy, finding a strong correlation in the early lockdown phase. This association weakened over time, suggesting that increased public awareness and compliance to precautionary measures mitigated the potential rise in R_t despite the increase in mobility. This indicated that while mobility restrictions effectively reduced virus transmission initially, long-term outcomes also depended on public behavior and awareness.

2.2 Finland's NPI Approach

Regarding the impact of movement restrictions in Finland, research is sparse. Nevertheless, adjacent studies provided insight into this area. For instance, Hakola-Uusitalo et al. (2020) utilized Google's mobility trend data to examine the effects of early interventions against COVID-19, comparing Finland's mobility with other Nordic countries. The study found that mobility, especially to retail and recreation venues, workplaces, and public transport, significantly decreased following the first recommendations on March 12, 2020. However, mobility in parks increased, suggesting a shift towards outdoor activities due to indoor restrictions. Interestingly, the study also indicated that the Uusimaa lockdown did not have a significant impact on mobility. The second study, by Willberg et al. (2021), focused on the movement between urban and rural areas, highlighting the Finnish tendency to retreat to secondary homes during the pandemic's first wave. Despite government advice against such movements, data showed a significant population increase in rural municipalities with many holiday cottages, also indicating a substantial urban-to-rural mobility shift.

3 Methodology

3.1 Mobility and COVID-19 data

To effectively examine the impact of movement restrictions on the spread of COVID-19, it is essential to analyze mobility data in conjunction with data on the virus's spread. Numerous methods exist for measuring mobility, with mobile network analysis being the most common. Yet, due to the unavailability of such data, we opted to use traffic data as a practical alternative. The Finnish Transport Infrastructure Agency (FTIA) gathers road traffic data through more than 500 traffic monitoring systems (TMS) positioned across Finland's road network. These TMS units, consisting of electrically conducting loops embedded in the pavement, record each vehicle that passes over them. This methodology aligns perfectly with the objectives of this case study, especially since numerous TMS units are situated near the Uusimaa border, providing precise traffic flow measurements. For this case study, TMS data from six out of the seven major roads crossing the Uusimaa border were utilized. The specific TMS locations used in this study are depicted in Figure 1. For our analysis, we combined the traffic volumes from each station on a daily level.

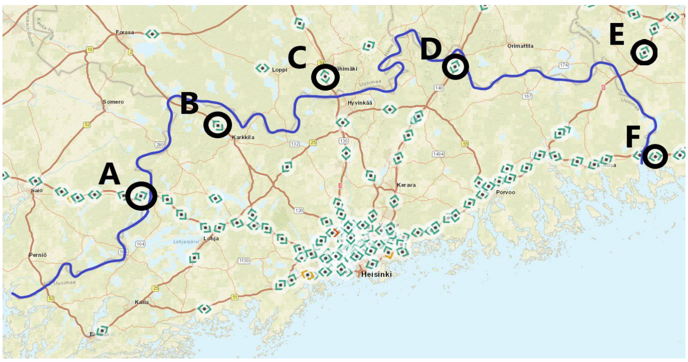

Figure 1: The border of Uusimaa and the TMS locations utilized in this study.
Source: https://liikennetilanne.fintraffic.fi/kartta/

The monitoring of COVID-19's spread can be approached through various methods, such as observing excess mortality rates. However, the most widely used method, which is adopted in this case study, involves tracking daily new confirmed cases of COVID-19. The spread of COVID-19 was quantified using data provided by the Finnish Institute for Health and Welfare. Analysis of the daily case data was conducted across different regional groups. However, given that the primary goal of the Uusimaa lockdown was to prevent the virus's spread from Uusimaa to other areas, the most essential focus was on all regions outside of Uusimaa. To reveal underlying trends more accurately, both the traffic and COVID-19 data were smoothed using a five-day moving average.

3.2 Visual and Statistical Analysis

In our analysis, we first applied visual analytics, enhancing our ability to discern patterns and correlations within datasets. Visual analytics facilitates an exploration of the combined mobility and COVID-19 datasets, offering a dynamic approach to identify and visualize temporal trends and anomalies (Cui, 2020). This method supports an intuitive understanding of how mobility changes may relate to fluctuations in COVID-19 case numbers.

To complement the insights gained from the visual analytics, we employed the Poisson regression model to analyze the impact of the lockdown and human mobility out of Uusimaa on the number of cases reported outside Uusimaa. Poisson regression was selected because it is a widely used general linear model for predicting non-negative integer values, or counts. We fitted a Poisson regression model to the abovementioned data on mobility and COVID-19 incidence, utilizing the following link function:

$$\log[E(Y_t)] = \beta_0 + \beta_1 Y_{t-7} + \beta_2 \omega_t + \beta_3 X_{t-6} \quad (1)$$

where

- Y_t represents the daily number of new cases in other parts of Finland outside of the Uusimaa region on day t
- Y_{t-7} represents the daily number of new cases in other parts of Finland outside of the Uusimaa region seven days prior to day t
- ω_t is a binary variable, which is 1 if the lockdown was in place on day t and 0 otherwise
- X_{t-6} represents the daily number (in thousands) of human mobility out of the Uusimaa region six days prior to day t.

Our statistical analysis exploited the knowledge on the doubling time of the COVID-19 epidemic, and the biological lag between virus transmission and the appearance of the first symptoms (i.e., the incubation period). Evidence suggests that, in its early stages, the epidemic doubled in size about every seven days (Li et al., 2020). The exact incubation period for COVID-19 remains unclear as original chain-of-infection data may not be fully accessible. Nevertheless, multiple studies (Backer et al., 2020; Men et al., 2023) exploiting confirmed cases in China in the early outbreak phase report a mean incubation period of six days.

4 Results

4.1 Visual Analytics of Mobility Data and COVID-19 Cases

The study aimed to evaluate the impact of restrictions on COVID-19's spread beyond Uusimaa. Therefore, we focused exclusively on outflowing traffic from Uusimaa and COVID-19 cases outside of Uusimaa during the period of March 1, 2020, to May 31, 2020. Figure 2 shows the results for the traffic data, where the blue bar indicates the daily traffic volumes, and the black line indicates the five-day moving average. Also, key moments are highlighted: the first black dot marks the announcement of initial government recommendations on March 12, and the second dot represents March 17, when further COVID-related restrictions were imposed. The horizontal red line outlines the duration of the Uusimaa lockdown.

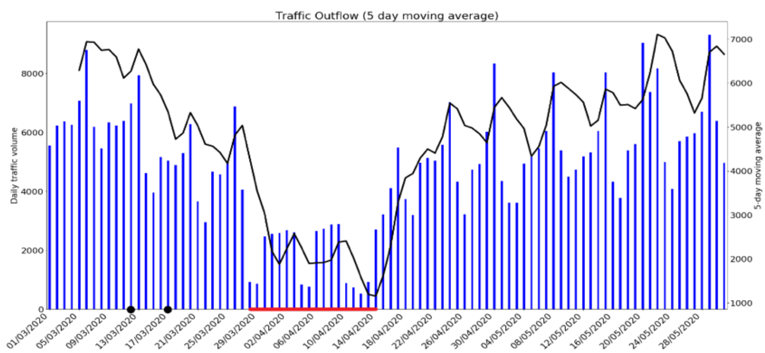

Figure 2: Outflowing traffic from the Uusimaa region

The analysis reveals that outbound mobility began to decline following the initial recommendations on March 12. Subsequent restrictions introduced on March 17 had no additional effect on the already decreasing outflow of traffic. A notable decrease in mobility occurred with the onset of the Uusimaa lockdown on March 28. Mobility levels remained substantially low until the lifting of the lockdown on April 15.

In Figure 3, the compilation of daily COVID-19 cases from hospital districts outside of Uusimaa is displayed as blue bars, with a five-day moving average depicted by the black line. The figure shows a very sharp increase in cases between March 17 and April 3. A few days after the peak, the number of daily cases decreased at a nearly similar rate as it increased.

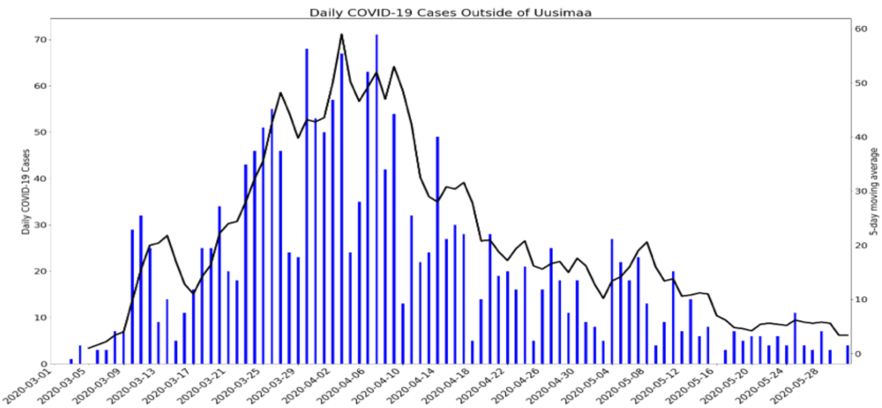

Figure 3: New confirmed cases of COVID-19 outside of Uusimaa

4.2 Analysis of Changes in Mobility and COVID-19 Cases

Figure 4 illustrates the relationship between mobility trends and confirmed cases of COVID-19, with the start and end dates of the Uusimaa lockdown outlined by two vertical black lines. The figure suggests a relationship between mobility and case numbers. It seems that a reduction in mobility to a certain threshold causes a subsequent decrease in COVID-19 cases, with a time lag before this impact becomes apparent.

4.3 Estimated Effects of Lockdown and Mobility

The summary for the Poisson regression model fitted to estimate the daily number of new cases outside Uusimaa is shown in Table 1. These results indicate that all selected independent variables in (1) have a statistically significant relationship with the number of cases reported outside Uusimaa. Interestingly, the coefficient associated with lockdown_Yes_No[T.Yes] (ω_t in (1)) is positive, which indicates that enforcing the Uusimaa lockdown will result in a 60.43% increase in the number of new cases in other regions on average. The outcome, while initially seeming paradoxical, is in alignment with the empirical evidence delineated in Figure 4. This figure illustrates that the number of daily COVID-19 cases continued to climb following the initiation of the lockdown, and it wasn't until approximately two weeks later that a decline was observed.

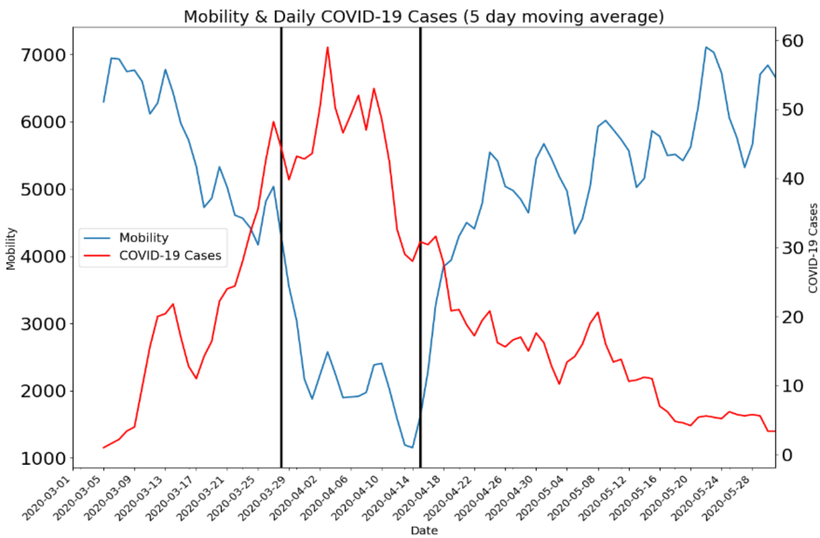

Figure 4: Outflowing mobility from Uusimaa and new COVID-19 cases.

Table 3: Results for the Poisson regression model

	coef	std err	z	P>|z|	[0.025	0.975]
Intercept	2.2955	0.089	25.675	0.000	2.120	2.471
lockdown_Yes_No[T.Yes]	0.4727	0.074	6.425	0.000	0.328	0.617
Count_t_minus_7	0.0181	0.002	10.554	0.000	0.015	0.022
mobility_t_minus_6	0.0366	0.014	2.633	0.008	0.009	0.064

5 Discussion

To answer the research question "Is there a relationship between change in mobility and the number of new cases?" a case study was conducted. The findings indicate that there was a rising trend in daily COVID-19 cases leading up to the Uusimaa lockdown. Following the implementation of the lockdown, there was a significant drop in traffic volume. Approximately two weeks elapsed before the peak in

COVID-19 cases was reached and soon after the peak, the trend started to decline. After the lockdown was lifted on April 15, traffic volumes quickly rebounded, nearly to pre-lockdown levels. Yet, the case study revealed no corresponding increase in COVID-19 cases. These results mirror previous research by Santamaria et al. (2020).

Thus, it appears that the restrictions were able to reduce the spread of COVID-19 in the short term, despite the increased mobility after the lifting of movement restrictions. Santamaria et al. (2020) argued that this was due to increased compliance with preventive measures. Similarly, Haug et al. (2020) suggested in their study that no individual NPI managed to reduce R_t below 1. While the Uusimaa case study did not specifically explore this factor, it's plausible that heightened public awareness and compliance played a role. Furthermore, it should be acknowledged that other restrictive measures were implemented before and during the Uusimaa lockdown and were not lifted at the end of the lockdown, which likely have had an impact.

Even though the results of the Uusimaa case study aligned well with the European and Scandinavian research, differences can be found in the study on China by Quilty et al. (2020). In China, the effect was minimal and only temporary (Quilty et al., 2020), while in Europe, the lifting of the lockdown did not result in an increase in cases. Potential explanations for this discrepancy are differences in the size of the population, culture, and demographics, to name a few.

The study also examined traffic volumes by vehicle type, as TMSs' are capable of differentiating cars, buses, trucks, etc., which yielded intriguing insights, particularly regarding bus traffic. The volume started to decline around the time the first recommendations were announced and continued to decrease at a linear pace until the end of the lockdown. However, bus traffic showed minimal evidence of recovery after the lockdown ended, suggesting a continued reluctance among the public to use crowded modes of transportation. While this case study spans from March 1, 2020, to May 31, 2020, making long-term trends indeterminate, the enduring effects on bus traffic patterns present a compelling subject for future research.

It is essential to acknowledge several limitations associated with the Uusimaa case study. The sample size is relatively small when compared to similar studies. For instance, the incidence of COVID-19 cases in Finland was significantly lower than that reported for other countries discussed in the literature review. In addition, as was mentioned earlier, to achieve a more accurate measurement of mobility, mobile phone positioning data could have been used, rather than relying solely on movement occurring on public roads, since it is impossible to ensure how many individuals are traveling in each vehicle. Although the Uusimaa case study has certain limitations, the results align closely with other relevant research, providing robust evidence in support of answering the research question.

As noted earlier in this chapter, the exact cause of the differing effects of movement restrictions in European countries as opposed to China remains unidentified. Hence, further investigation is required to understand the underlying factors, be they geographical, demographic, or otherwise.

6 Conclusion

The findings suggest that the imposed movement restrictions in Finland, as well as in other European countries, effectively reduced human contact and successfully mitigated the spread of the virus. Moreover, the restrictions raised people's awareness of the ongoing situation, which led them to adopt other precautionary measures. These results suggest that mobility is a key element in reducing the spread of the virus in the initial phase of an outbreak, but its effect diminishes as other restriction measures are in place.

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