Article

Forecasted Incidence, Intensive Care Unit Admissions and Projected Mortality attributable to Covid-19 in Portugal, UK, Germany, Italy and France – 4 weeks Ahead

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Abstract: The use of Artificial Neural Networks (ANN) is a great contribution to medical studies since the application of forecasting concepts allows the analysis of future diseases propagations. In this context, this paper presents a study of the new coronavirus SARS-COV-2 with a focus on verifying the virus propagation associated with mitigation procedures and massive vaccination campaigns. There were proposed two methodologies to predict 28 days ahead the number of new cases, deaths, and ICU patients of five European countries: Portugal, France, Italy, United Kingdom, and Germany, and a case study of the results of massive immunization in Israel. The data input of cases, deaths, and daily ICU patients was normalized to reduce discrepant numbers due to the countries size, and the cumulative vaccination values by the percentage of population immunized, at least with one dose of vaccine. As a comparative criterion, the calculation of the mean absolute error (MAE) of all predictions presents the best methodology and targets other possibilities of use for the proposed method. The best architecture achieved a general MAE for the 1 to 28 days ahead forecast lower than 30 cases, 0,6 deaths and 2,5 ICU patients by million people.

Keywords: Time Series Prediction; ANN forecasting; New Coronavirus; COVID19 prediction cases; COVID19 prediction deaths; COVID19 prediction ICU, COVID19 Vaccination; COVID19 in Europe; COVID19 in Israel; COVID19 use of face mask.

1. Introduction

The pandemic declaration by World Health Organization (WHO) in March 2020 presented the world with the great challenge of controlling the disease caused by the new coronavirus, discovered in Wuhan in 2019. The race between nations for the study and approval of medicines and vaccines has started. This resulted in achieved public and private investments to streamline the stages of development [1].

In the research context, the effectiveness of drugs already on the market as possible treatments was evaluated [2]. However, despite the insistence of some political fronts, these drugs have been under discussion for too long even though their ineffectiveness has been proven and causing long-term damage to people who used them without medical advice. A controversial example is Hydroxochloroquine, used in the treatment of Lupus, Malaria, and Rheumatoid Arthritis. Further tests have shown the drug to be ineffective in reducing the risk of patients having respiratory problems and subsequently being placed on ventilators [3]. To this date, the treatment of Covid-19 is carried out by the individual assessment of each patient, without a single treatment protocol, not yet established.

The advent of several vaccines happened in the second semester of 2020. Despite the suspicion about the effectiveness of immunizers due to the short time they spent on studies and tests, the rapid development was carried out with the help of previous research on coronaviruses and innovative technologies, whose development lasted two decades, and the increased focused funding received on the last couple of years. Says Dr. Cristina Toscano, WHO correspondent, in an interview.

Some authors already proposed by the use of time series forecasting applied to predict data about coronavirus propagation. In [4] the multilayer perceptron network is trained with thirty countries data using the previous 20 days of new and accumulative number of cases and deaths to predict accumulative cases and deaths for six days ahead. Similarly, the methodology proposed in [5] uses a combination of eight countries data of the accumulative number of cases and deaths applied to two training algorithms, Levenberg-Marquardt, and the Resilient Propagation to predict seven days of accumulative cases and deaths for Portugal, Brazil and USA. Focused more in Asian countries to train, [6] used three different analyses to propose a method to predict the accumulative number of cases for ten days in India, USA, France and UK, while [7] use a deep architecture, with NAdam training model to forecast fourteen days for several countries and regions of accumulative number of cases. Meanwhile, the methodology proposed in this paper predicts data for twenty-eight days for the daily number of new cases, deaths, and ICU patients, not accumulative values as the previous methods and used information about the use of face mask and the vaccination situation in each country.

Within the context of mass immunization in several countries, this article presents a study of the spread of Covid-19 in Europe and includes an analysis of the prediction of new cases, deaths, and ICU patients, based on two analytical approaches applied to artificial neural networks. The algorithms used adopted a direct forecasting approach for several days (n is the next day): n to n + 6, n + 7 to n+13, n + 14 to n+20, and n + 21 to n+27 days ahead, and a recursive approach for a range of 28 days, in order to compare the results of the approaches. Both set serve to analyze the spread of the virus associated with methods of mitigation and mass immunization.

The description of methodologies used to predict new cases, deaths, and ICU patients will be detailed in the section 2. The normalization of the data was carried out per million people of each country to reduce the discrepancies of absolute numbers, thus allowing a clearer analysis as to the effectiveness of the mitigation methods. Also, a moving average of seven days was applied to the data, to minimize errors by underreporting on weekends.

Besides, a case study is presented on new infections and deaths in Israel and the consequences of quick vaccination. It is important to highlight that vaccination in Israel is carried out exclusively with the immunizer developed by the partnership between Biontech and the Pfizer group, which facilitated the percentage analysis of the efficacy of the immunological window [8].

This manuscript is organized into an introduction, the presentation of material and methodologies with an analysis of the virus propagation on six countries, plus a case study of Israel. It follows the presentation of results of the mass vaccination campaign, the results of forecasting new cases, deaths, and ICU patients for the six countries and the case study using different approaches. The same secctio includes the discussion and comparison of the different methodologies and the results. The manuscript finalizes with the conclusions section.

2. Materials and Methods

The present study aimed to analyze the waves of new cases, deaths, and ICU patients of Covid-19. The Time series data were normalized per million people of each country in order analyze the virus propagation independently of the size of the country.

Moreover, two methodologies of forecasting were proposed, defined by: 1) 'Recursive Approach', and 2) 'N approach'.

Both forecasting methodologies use previous data of 21 days before (n-21 : n-1), related to: number of new cases, number of deaths, number of ICU patients, information about the mandatory use of masks at previous day (n-1), and the percentage of immunized people at least with the first dose of a vaccine.

The models are used to predict the number of new cases, deaths and ICU for next days. In the recursive approach, the previous 21 days are used to predict only one day ahead (n), then the data are update with predicted numbers to predict the next day, in a recursive iteration, until the desired number of days ahead. With the N approach, the ANN model uses the same previous 21 days, but the output is the predicted numbers for a range of days ahead, from n (next day) to n+7, n+14, and n+ 21, using four outputs (one for each week ahead), and recursively determine the 7 day of the week.

2.1. Data collection source

For the development of this work, the established database to train, validate and test the ANN, includes qualitative and quantitative data, associated with the period between January 25th of 2020 and March 14th of 2021. The quantitative data used are related to daily new cases and deaths, the daily number of ICU patients and, the percentage number of people immunized with the first dose of vaccine. On the other hand, the qualitative data used in the study is associated with the mitigation procedures, specifically the mandatory use of masks. The data about lockdown on the countries were not available to be applied as an input, since the restrictions were defined with different levels and conditions for each country and sometimes with differences inside the country.

The proposed forecasting methodology of Covid-19 new cases, deaths, and ICU patients is based on analyses of five European countries, namely Portugal, France, Italy, UK, and Germany. However, at the beginning of tests, Israel was also included, since, at the time, it was the country with higher level of immunization with a mass vaccination campaign.

The data gather was oriented mainly by Worldometer and Ourworldindata websites [9], both used as references by media such as Johns Hopkins CSSE, Financial Times, The New York Times, and Business Insider. The websites combine the information provided from the official media platforms of each country to simplify analyses on the same platform. [10]–[15]

For the information about the use of masks, the chosen source was the website 'mask4all' [16], that report when the use of masks started being mandatory in public places in each country. The information input to the ANN assumes a value 1 from the date when the masks began being used as a mandatory precaution, and 0 before that date.

2.2. Data processing

The absolute numbers of the new cases, deaths, and ICU patients are directly related to the size country's population. Therefore, it is necessary to normalize the daily numbers by a standard for all countries. The normalization method was by million people, dividing each daily number by the population of the respective country (in millions without rounding). In order to reduce oscillatory data, caused by weekend underreporting, was also applied a moving average of seven days.

The accumulative vaccination data used as input refer to the last day before the prediction and was defined as a percentage of the population of each country that received at least one shot of vaccination. Finally, the qualitative data, about the use of masks, does not require a normalization since it is binary and refers to the last day before the first prediction (n-1). The inputs of each ANN architecture are composed of 70 nodes, being 5 nodes for country binary identification, and the last 65 for all quantitative and qualitative data, corresponding to the 21 previous days (n-21 to n-1) for cases, deaths and ICU numbers, plus the use of mask and the vaccination number in previous day (n-1).

The dataset were divide for training and validation and for testing procedures. The data related to January 25th of 2020 until February 14th of 2021, of all countries under study, were combined and divided randomly in 75% for training and 25% for validation. In the training stage, the ANN learns the time-series behavior using the training data, and the validation dataset is used to stop training early avoiding overfitting. The data from February 15th to March 14th 2021 was separated for test dataset. The test dataset were not seen by the model during the training procedure and was used only to evaluate the model performance.

2.3. Recursive approach

In this approach, illustrated in Figure 1, the daily numbers of cases, deaths, and ICU patients are forecasted for the period between February 15th and March 14th of 2021 (test dataset), for Portugal, France, Italy, UK, and Germany. The Multi-Layer-Perceptron ANN architecture was used as the computational tool for the prediction of the mentioned data. Since the behavior of the time series of deaths, ICU and cases tend to have a delay between each other, one ANN was used for each of this time series, but the same for all countries. Anyhow, the input and methodology is the same for the three ANNs.

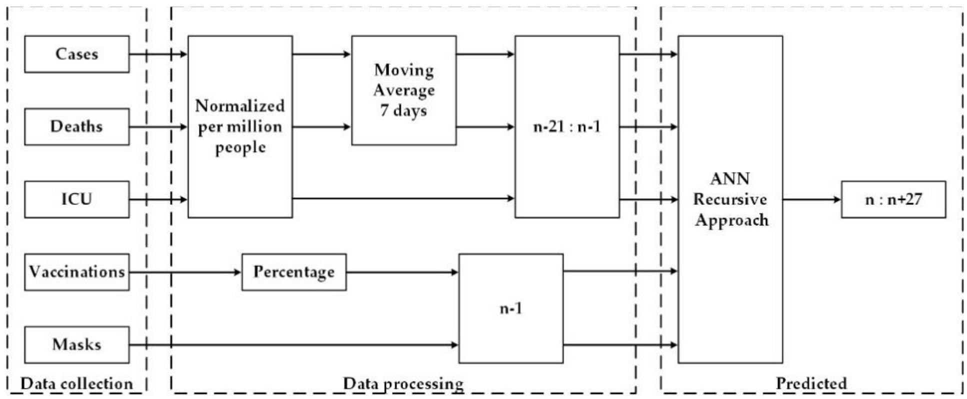

Figure 1. Prediction diagram for the 3 ANN (cases, deaths and ICU) – recursive approach

The forecasting methodology of this approach consists in predict the new number of cases, deaths, and daily ICU patients by one day ahead, related to the data used as input. The predictions are used in the next iterations for next day.

Several Architectures combination were experimented using the training/validation dataset. For the three ANN used to forecast, the best topology has only one hidden layer with different numbers of neurons in hidden layer, and activation functions in hidden and output layers. All experiments used the Levenberg-Marquardt training algorithm [17]. The best architecture for each situation is shown in Table 1, and are the ones adopted for this approach.

Table 1. Best ANN topology - Recursive approach

Predicted Data	HL #Neurons	HL Function	OL Function
Cases	4	Elliot	Linear
Deaths	13	Elliot	Linear
ICU	13	Elliot	Linear

HL: Hidden Layer, OL: Output Layer

2.4. N approach

This approach proposes to predict the new cases, deaths, and daily ICU patients of the same period of the previous approach. However, in this case, the forecasting total vector is divided by week, and its schematic is shown in Figure 2.

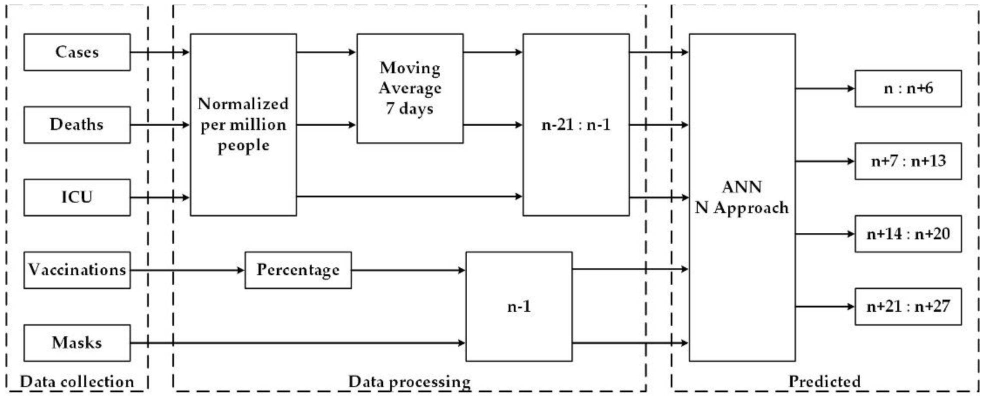

Figure 2. Prediction diagram – N approach

The forecasting methodology of this approach consists of forecasting new cases, deaths, and ICU patients (one ANN for each), for days n (first day), n+7, n+14 and n+21. The input for each ANN has 70 nodes (detailed in section 2.2) to code the country, new cases, deaths, ICU patients, vaccination, and mandatory use of masks. Each ANN has 4 outputs. The prediction is made in a sequences of seven, which result in the forecast of the following days for each output of the ANN: n to n+6, in the node 1; n+7 to n+13, in node 2; n+14 to n+20, in node 3 and n+21 to n+27 in node 4. For the present experiment, the following days were predicted in each of the four nodes:

- First day (n): February 15th, 2021 to February 21st, 2021
- Eighth day (n + 7): February 22nd, 2021 to February 28th, 2021
- Fifteenth day (n + 14): March 1st, 2021 to March 7th, 2021
- Twenty-second day (n + 21): March 8th, 2021 to March 14th, 2021

Similar to the recursive approach, three separate ANN are used to forecasting using only one hidden layer, different numbers of neurons in hidden layer, different activation functions in the hidden and output layers, and Levenberg-Marquardt as the training algorithm [17]. The best architecture for each situation is presented in Table 2.

Table 2. Best ANN topology - N approach

Predicted Data	HL Neurons	HL Function	OL Function
Cases	4	Elliot	Linear
Deaths	18	Elliot	Linear
ICU	15	Elliot	Linear

2.5. Error measurement

To compare the recursive and N approaches, the Mean Absolute Error (MAE) for each methodology is calculated by the Equation 1, to predict new cases, deaths, and ICU patients for the followed week cases:

- Between February 15th, 2021 and February 21st, 2021 (next week)
- Between February 22th, 2021 and February 28th, 2021 (two weeks ahead)
- Between March 1st, 2021 and March 7th, 2021 (three weeks ahead)
- Between March 8th, 2021 and March 14th, 2021 (four weeks ahead)
- Between February 15th, 2021 and March 14th, 2021(next month)

$$MAE = \frac{1}{n}\sum |Real - Predicted| \quad (1)$$

3. Analysis, Results and Discussion

The analysis of the cases and deaths for the European Countries and Israel is presented in following subsection. Since the behavior of the Israel's time series is different from the ones of the European countries, they were excluded from the dataset to train the prediction model. Anyhow, some analysis of the time series of Israel are presented in section 3.2, as a case study. The results of the predicted values using the Recursive and N approaches are presented in sections 3.3, 3.4, and 3.5. Section 3.6 is devoted to the discussion.

3.1. Daily numbers of cases and deaths

After the normalization by million people and smooth with seven days moving average, Figure 3Figure 4 displays the behavior of the contamination and deaths due to COVID-19 on the six countries. It is possible to point out the three waves of daily new infections and deaths for European countries and four waves in Israel. The waves in European countries are more or less synchronized but Israel shows different behavior. The chosen range of countries, composed by five European countries and Israel, were defined to verify the results of similar mitigation procedures, adopted by the European Union and the United Kingdom, and Israel since this country has the one more advance in vaccination.

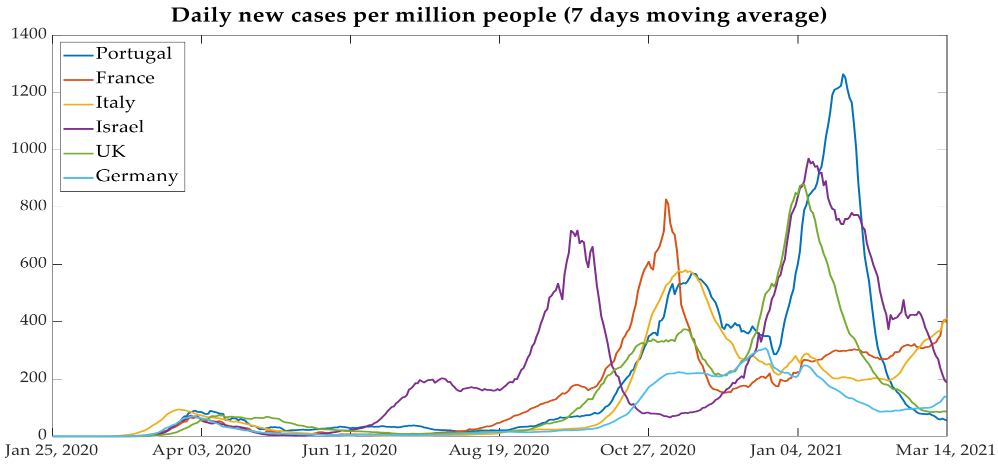

Figure 3. New cases - normalized by million people.

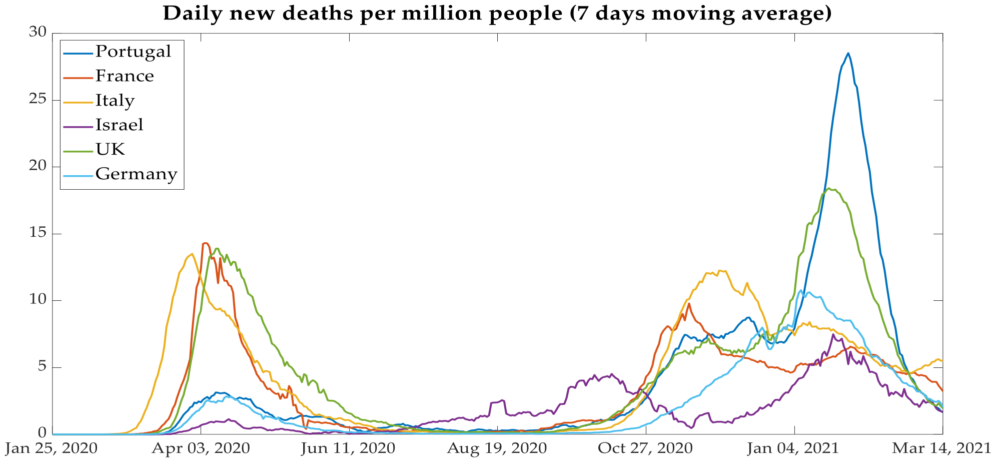

Figure 4. New deaths - normalized by million people.

The similarities among the contagion curves of the European Union and the United Kingdom are results of mitigation actions that were taken by mutual agreement, even with the exit of the United Kingdom from European Union in January 2020 (Brexit).

In a comparative analysis between Portugal and United Kingdom is possible to note similarities in the second and third wave, where the behavior of daily new cases and deaths are very similar. That fact can be associated with the B.1.1.7 variant (known as UK COVIV-19 variant), which shown itself as more contagious than the non-variant strains, and represented 40% of total Portuguese cases, and 60% of cases in the region of *Lisboa e Vale do Tejo* until February of 2021 [18]–[20]. However, in the next month the variant reached the mark of 82,9% of Portuguese cases [21]. Another similarity between those countries was the relaxation of contingency rules during the Christmas holidays.

Analyzing the third wave is possible to notice that countries that adopted lockdown during the month of November and December, like Germany and France, had less pronounced curves of new daily cases and deaths, per million people. However, even Italy had adopted relaxed measures similar to Portugal and UK during the holidays and had no pronounced curve of new cases and deaths.

3.2. Israel: a case study

The Middle-Eastern country Israel was taken as an important case to study since it has shown itself as very advanced on the vaccination process. From the analysis of data on new cases and deaths presented in Figure 3Figure 4, it is possible to observe that the case of Israel has a different behavior from the European countries also used in the present study. Some notes regarding the behavior of the curves under analysis per million people. Israel had a second wave before European Countries between July and August, and the third wave of contamination occurred between the second week of September and the first week of November, while European countries, except for Germany, had the second wave between the second week of October and the beginning of December.

In this way, Israel was taken out from the join analysis and was analyzed as an individual case study. The importance to analyze Israel is due to the highest percentage of people vaccinated in a short period. The start of vaccination in the country began on December 19th of 2020 and reached the achievement of 1 million people vaccinated, with the first dose, on January 1st of 2021 [22], [23]. The results of mass immunization can be seen in the curves of new cases, presented in Figure 5, but it is worth some considerations.

Vaccination in Israel has been, so far, exclusively through the immunizer produced in partnership between Biotech and Pfizer, which proved to be 95% effective in the second and third phase of the clinical study, carried out in terms of randomized, observer-blind, and placebo control [8], [22], [24], [25].

According to the preprint released by Technion (Israel Institute of Technology), the analyses carried out after the start of the vaccination, analyzed between December 19th and February 25th, show a gradual reduction in the rate of infection from 12 days after the application of the first dose, stabilizing on day 35. This results in a reduction in the viral load due to vaccines after 12 days, which makes it harder for the virus to infect new individuals [8], [25].

Since the virus has an incubation period ranging from 2 to 14 days [9], a drastic reduction in the number of new cases was expected from the second week of January (14th January, labeled in Figure 5), corresponding to 12 days after 1 million people vaccinated, which was observed in the graph shown in Figure 5.

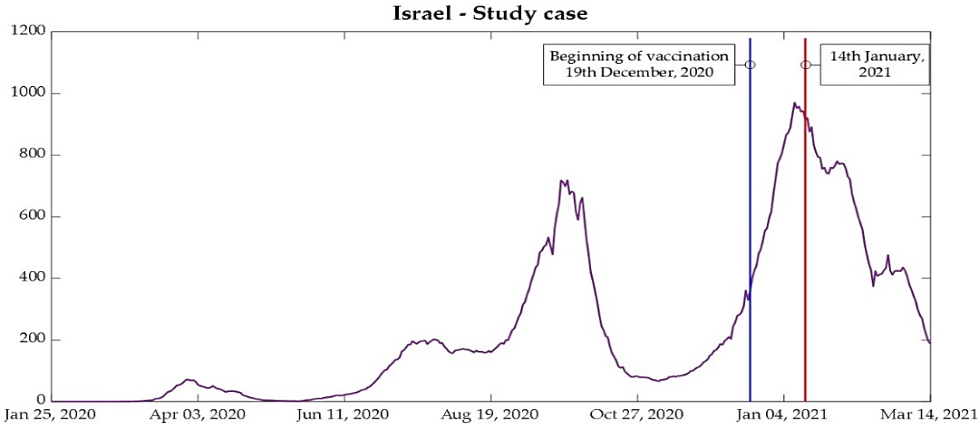

Figure 5. Israel daily new cases per million people.

Another point is that even after the beginning of flexibilization of lockdown in the country, adopted on February 21th after 45% of the population vaccinated with the first dose of the vaccine, the curve of new cases continues to reduce, alongside new deaths and ICU patients [23], [26].

The advanced vaccination in Israel, exclusively with Biotech-Pfizer immunizer, is directly associated with the deal between the government and the American company. According to The Times of Israel, the government would pay 43% more than the United States and European Union for the vaccine. Another important topic is that Israel should provide data results of mass vaccination, quantitative and qualitative, according to geographic region, age, and sex. Furthermore, Israel accepted to take the responsibility for the vaccine product, the opposite direction taken by European Union, that demand that the company still being responsible for the immunizer [22].

In the first week of April 2021, the company Pfizer and the Israeli government are working on a new vaccine supply, to continue selling doses for the country, and since the deal agreement, in November 2020, over 8 million doses were already produced [27]–[30]. It is important to highlight that, even the vaccination campaign being made exclusively in the country by the Biotech-Pfizer immunizer, the government still has a deal with Moderna company, approved to use since January 2021 [27], [29].

3.3. Recursive approach results

As explained in subsection 2.3 the recursive approach predicts one day ahead, using data of new cases, deaths, and daily ICU patients of twenty-one days before, vaccination and the use of masks data one day before. This methodology updates the input data in each iteration with predicted values of previous iteration, creating a vector of twenty-eight days forecasted. Consequently, this approach accumulates errors because uses predicted values in ANN input since the second iteration.

The forecasting of new cases, deaths, and daily ICU patients were made in a separate ANNs. Each ANN do forecasting for the five European countries. Only the prediction for the 28 days of the test set are considered in further analysis. The all presented data are normalized by a million of people.

The results of Portugal and UK were analyzed together, since the B 1.1.7 Covid-19 variant already represents 82,9% of Portuguese nationwide cases [21]. However, the mass vaccination campaign in the UK is showing itself faster than the Portuguese campaign, which results in a divergence of real and forecasted values [31].

In Figure 6 is presented Portuguese new cases, in blue, and it is possible to note that the ANN predicted to Portugal an abrupt decrease followed by an increase in new daily cases, which can be explained by the training data. The model predicted a new wave similarly the new wave after the second wave. Maybe this new wave has been avoided by the strong lockdown after 22nd January. For the world data this new wave started in the middle of February [9].

On the other hand, for the UK cases, shown by green curves in Figure 6 the gap between the real and predicted cases to UK after February 24th. The divergence present in the plot is justified by the quick vaccination in UK, which reached more than 30% of the population vaccinated with the first dose of vaccine on March 1st. Is it important to highlight that UK used, so far, Biotech-Pfizer and Astra-Zeneca immunizer, both with respectively efficiency of 95% and 76% [8], [32]–[36].

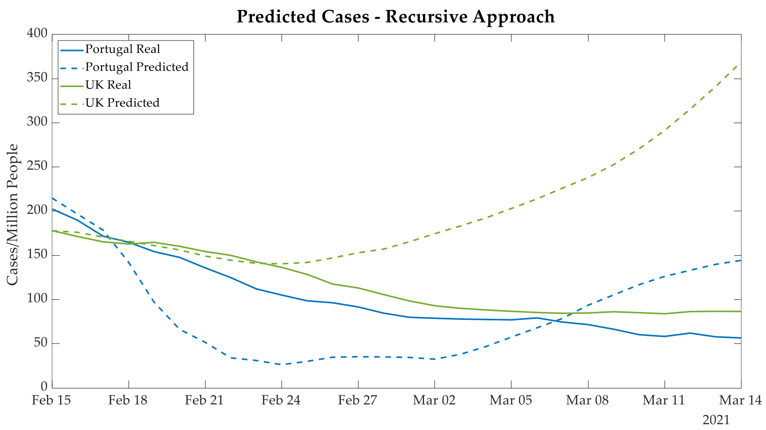

Figure 6. Portugal and UK new cases - Recursive Approach

The deaths and ICU patients' forecasting results to Portugal, followed the same tendency as the real data, as shown in Figure 7Figure 8, demonstrating a good prediction until February 18th, and satisfactory results for the next 24 days.

The gap tendency, verified in UK new cases curves, between real and predicted values is also verified on deaths and ICU patients' curves, as demonstrated also the Figure 7 andFigure *8*.

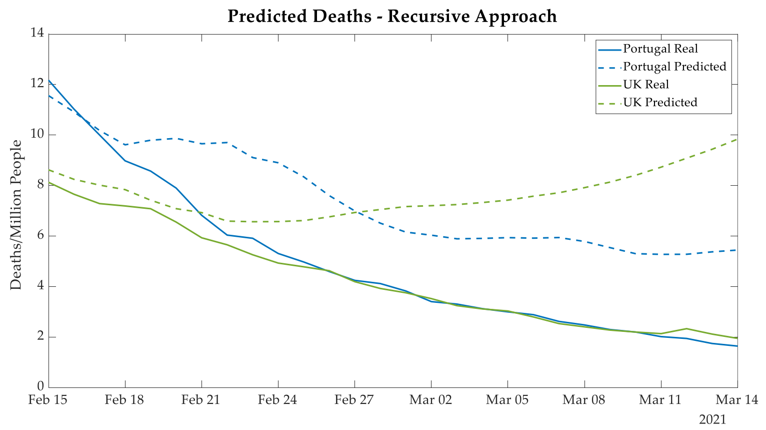

Figure 7. Portugal and UK new deaths - Recursive Approach

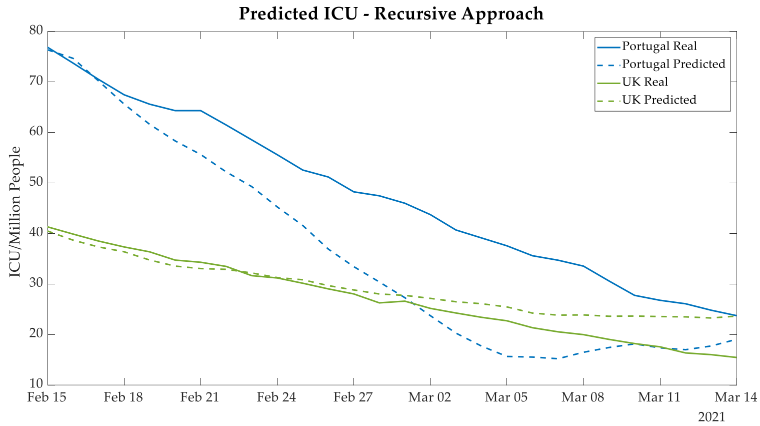

Figure 8. Portugal and UK daily ICU patients - Recursive Approach

The Figures A1, A2 and A3 in Appendix A show the other countries' prediction of new cases, deaths, and ICU patients, using the recursive approach. The best results were defined by the analyses of MAE in order to verify the best ANN topology.

3.4. N approach results

The second approach to predict the new cases, deaths, and daily ICU patients had a methodology that uses the same input data as the last one, but the forecasting values were defined directly by the prediction of n, n+7, n+14, and n+21 days, used to create a vector of seven days ahead each.

The greatest advantage of the N approach is it does not accumulate errors by iteration, since the prediction is direct obtained from real data. However, since it used a limited database the main error source came from the values of the daily variation, even with the moving averages. The tendency of new cases in Portugal and UK, shown in Figure 9, has a significant variation among days, which were expected due to the variation in the training data. Anyhow the UK predition behaves quity well.

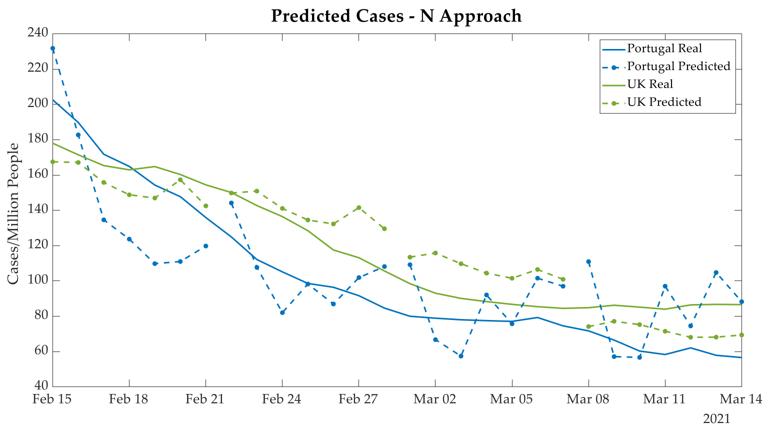

Figure 9. Portugal and UK new cases - N Approach

In Figure 10Figure 11, the plots demonstrate very good results in the deaths and ICU patients forecasting, respectively for Portugal and UK. The absolute errors increase substantially only in n+21 analysis, which can be explained by the distance between the predicted values and the real data known by the ANN. Another point is that the tendency of deaths followed the ICU patients, which is expected since the ICUs represent the serious cases of Covid-19, and unfortunately, sometimes those cases resulted in death.

Analyzing UK prediction, in Figure 9, Figure ***10***, and Figure ***11*** the results of UK demonstrate that the N approach was better in forecasting than the recursive approach since it followed the tendency of new cases, deaths, and daily ICU patients, without a substantial gap, demonstrated in the previous approach. The comparative analyses of the two approaches will be discussed in subsection 3.6.

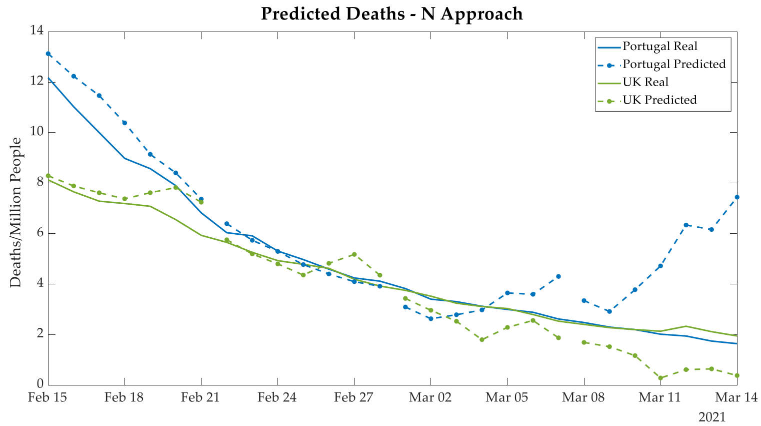

Figure 10. Portugal and UK new deaths - N Approach

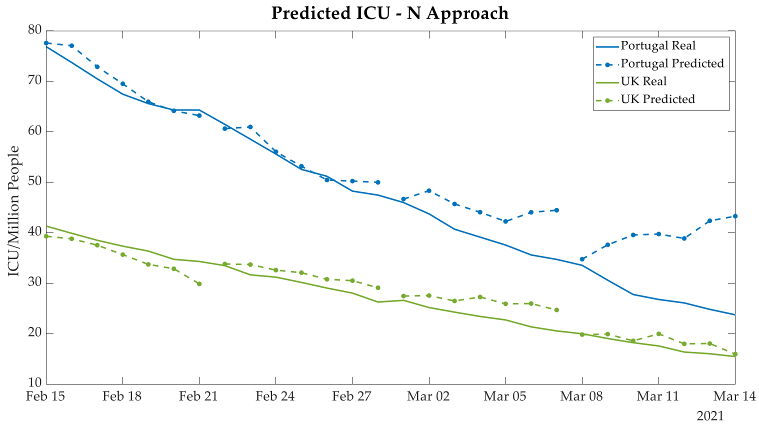

Figure 11. Portugal and UK daily ICU patients - N Approach

The plots that shown the predicted values of France, Italy, and Germany are presented in Appendix B, Figures B1, B2 and B3.

3.5. Comparizon of forecasting approaches

The two proposed forecasting methodologies were analyzed by an mean absolute error over the test set (1 to 28 days ahead) for the 5 European countries, for the 3 parameters (cases, deaths and ICU patients), as shown in Table 3. The MAE is presented for each week ahead and for the whole 4 weeks ahead. The MAE presented is an absolute measure of the mean error by million people. Results are presented by country and for the all countries (Total).

Table 3. Mean Absolute Error - comparative analyses

	Recursive Approach			N Approach		
	Cases	Deaths	ICU	Cases	Deaths	ICU
Portugal n : n+6	38,83	1,08	3,18	30,29	0,95	1,45
Portugal n+7 : n+13	69,50	3,14	12,29	12,92	0,18	1,37
Portugal n+14 : n+20	28,16	2,80	20,29	17,52	0,75	5,44
Portugal n+21 : n+27	60,87	3,38	10,02	25,98	2,91	11,84
Portugal n : n+27	49,34	2,60	11,44	21,68	1,20	5,03
France n : n+6	10,23	0,63	2,35	8,18	0,20	1,03

France n+7 : n+13	14,44	1,27	9,39	13,03	0,47	0,46
France n+14 : n+20	21,86	1,41	18,00	32,41	0,24	3,03
France n+21 : n+27	27,02	2,44	21,42	19,34	1,60	8,51
France n : n+27	18,39	1,44	12,79	18,24	0,63	3,26
Italy n : n+6	13,79	0,74	0,26	4,07	0,12	1,10
Italy n+7 : n+13	18,99	1,71	0,07	38,29	0,37	0,61
Italy n+14 : n+20	14,88	0,90	1,84	63,37	0,47	0,85
Italy n+21 : n+27	56,70	0,57	6,38	94,47	0,22	4,77
Italy n : n+27	26,09	0,98	2,14	50,05	0,30	1,83
UK n : n+6	3,76	0,62	1,17	10,18	0,58	2,10
UK n+7 : n+13	20,84	1,96	0,72	12,32	0,60	1,82
UK n+14 : n+20	104,65	4,24	2,43	17,97	0,65	3,04
UK n+21 : n+27	211,18	6,59	6,08	13,75	1,30	1,13
UK n : n+27	85,11	3,35	2,60	13,56	0,71	2,02
Germany n : n+6	2,99	0,22	0,63	6,12	0,44	1,16
Germany n+7 : n+13	21,82	0,42	1,96	12,47	0,25	1,01
Germany n+14 : n+20	23,72	1,12	2,53	24,30	0,31	0,56
Germany n+21 : n+27	36,21	1,82	3,28	57,60	0,46	1,04
Germany n : n+27	21,19	0,89	2,10	25,12	0,37	0,94
Total n : n+6	13,90	0,67	1,31	10,49	0,40	1,32
Total n+7 : n+13	27,43	1,70	4,08	21,22	0,37	0,98
Total n+14 : n+20	34,69	1,90	7,82	36,49	0,48	2,30
Total n+21 : n+27	74,78	2,56	8,93	50,94	1,12	5,34
Total n : n+27	37,70	1,71	5,54	29,78	0,59	2,49

For the number of cases, the predictions made by each approach will be analyzed along the 5 countries. Generally it can be observed that the N Approach made better forecasting then Recursive Approach for Portugal, France and UK, but behaves worst for Italy and Germany, considering the for weeks together (n:n+27) and also for the long term prediction (fourth weeks ahead, n+21:n+27). Multiplying the predicted number by the population of the country, the long-term prediction (4 weeks ahead) is about 930 daily cases for UK (lower MAE), and 5670 for Italy (higher MAE), and 260 for Portugal. Regarding the MAE in the Total countries, the N Approach definitely made a better prediction, with a MAE lowes than 30 cases by million people.

Concerning number of deaths, the N Approach made better forecasting then Recursive Approach for the 5 countries. The MAE varies between 0,3 to 1,2 daily deaths by million people for the whole 4 weeks ahead. The forecasting for only the long term (4 weeks ahead) the MAE varies between 0,22, for Italy and 2,91 for Portugal. Considering the all population of the country is a daily MAE variation between 13 deaths in Italy and 29 in Portugal for the long-term forecasting. Regarding the MAE in the Total countries, the N Approach definitely made a better prediction, with a MAE lowes than 0,6 deaths by million people.

Also for the ICU patients prediction, the N Approach behave better then Recursive Approach for the five countries. The MAE varied since 0,94 for Germany and 5,03 for Portugal by million people for the whole 4 weeks ahead. Considering the long-term prediction this forecasting presented and MAE between 1,04 for Germany and 11,84 for Portugal. For the whole population of the country this represents a MAE between the total number 84 ICU patients in Germany and 118 ICU patients in Portugal. Regarding the MAE in the Total countries, the N Approach also made a better prediction, with a MAE lowes than 2,5 ICU patients by million people.

3.6. Discussion

Based on the analysis of the prediction made by the two Approaches it is clear an improved prediction made by the N Approach for the prediction of the deaths and ICU patients. For the number of cases, the N Approach also behaved better for 3 of the 5 countries. Therefore, this architecture of prediction demonstrated advantage over the Recursive Approach. This may be due to the error accumulation since day 2 in the Recursive Approach.

The use of ANN to predict the number of cases and deaths for next 6 [4], 7 [5], 10 [6] and 40 [7] days was already experimented but for accumulative values, with promising result using a recursive approach and a variety of countries. The results of present work cannot be compared to results of previous similar works because the relative error of the accumulative cases cannot be directly compared with the absolute error of daily predictions.

Concerning the MAE of the forecasting for the five European countries, Portugal presented the higher error in the predicted number of deaths and ICU patients maybe because of the strong decay caused by the strong lockdown just before the period used to the test set. The values of cases deaths and ICU patients for this country suffered an abrupt increase caused by relaxed rules during the Christmas period. These similar tendencies were observed in large Eur-Asian nations such as India and Russia with rather massive pool of vaccinated citizens during the same period [37]–[39].

It was expected that the virus propagation followed the same lead to all countries under study, however, due the variants and different severity of contingency rules, the plots presented a different perspective. As shown in previous sections, the behavior of new cases and deaths in Portugal and UK are similar, which is explained by the B 1.1.7 variant being more infectious [40].

Another association possible to make is between France and Germany since both countries adopted a restricted lockdown during November and December of 2020 [41] resulting in an attenuated third wave. Even in small island states such as Malta comparable challenges were observed [42].

4. Conclusions

The data analysis presented in this paper propose a review of the three waves of Covid-19 in European countries, associated with mitigations procedures. The main goal was to compare the vaccination campaigns and the results according to new infections deaths and ICU patients. In the first tests, Israel was considered to compound the study group although how the infections in the country had a different behavior compared to the other countries under analyzes, were taken out as a separate case study.

From this work is possible to analyze the coronavirus propagation waves considering the mitigation procedures and vaccination campaigns. One goal was to investigate the data normalized by million people in the country to be independent of the size of the country. The found results show the efficiency of a restricted lockdown to decrease the virus propagation and most of all, the efficiency of a massive vaccination campaign, following the WHO recommendation.

The experimented models used to predict the number of new daily cased of infection, deaths and ICU patients was based in two approach. The Recursive Approach made the prediction for next day in a recursive way until 28 days ahead. The N Approach made the perdition for one day of the next four weeks and recursively determines the other 6 days of each week. One ANN was used for each parameter, cases deaths and ICU patients, due to the delay between these time series, following se sequence of cases followed by ICU patients and later deaths. The ANN has the previous 21 day’s numbers of cases, deaths and ICI, plus the use of face mask and the percentage of population withy one doze of vaccine, at least, and the country identification, in its input. The ANN models made perdition for next days until 28 days ahead.

The N Approach presented improved forecasting performance for the 3 variables and was selected as the best Approach model. The MAE for the all period of the next 28 days for the five countries (Portugal, France, Italy, Uk and Germany) were lower than 30 cases, 0,6 deaths and 2,5 ICU patients by million people. The hardest forecasting for the long-term analysis of 4 weeks ahead only, behaved with a MAE below 51 cases, 1,2 deaths and 5,4 ICU per million people, that can be considered at the level of a reasonable forecasting to be considered by decision maker about the eventual future restriction.

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Data Availability Statement: The data about the time series of the number of cases, deaths and ICU patients, used in the research were extracted from: https://www.worldometers.info/corona-virus/?utm_campaign=homeAdUOA?Si, The data about vaccination were extracted from: https://ourworldindata.org/covid-vaccinations , The use of face mask data were extracted from: https://masks4all.co/pt/what-countries-require-masks-in-public/ .

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Recursive approach's results of daily new cases, deaths, and ICU patients to France, Italy, and Germany.

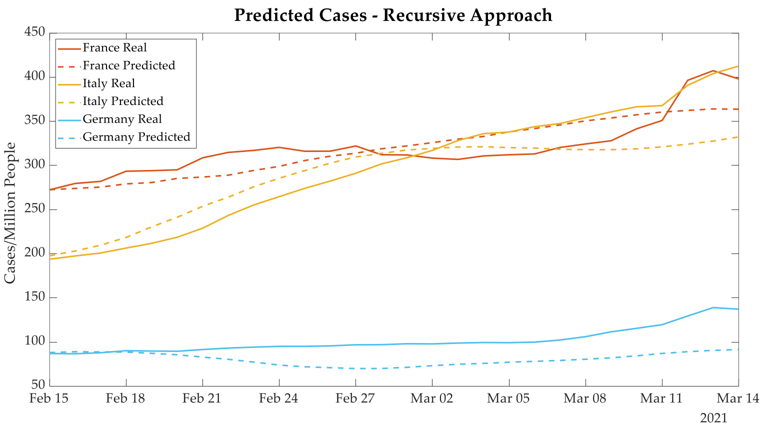

Figure A1. France, Italy, and Germany daily new cases - Recursive Approach

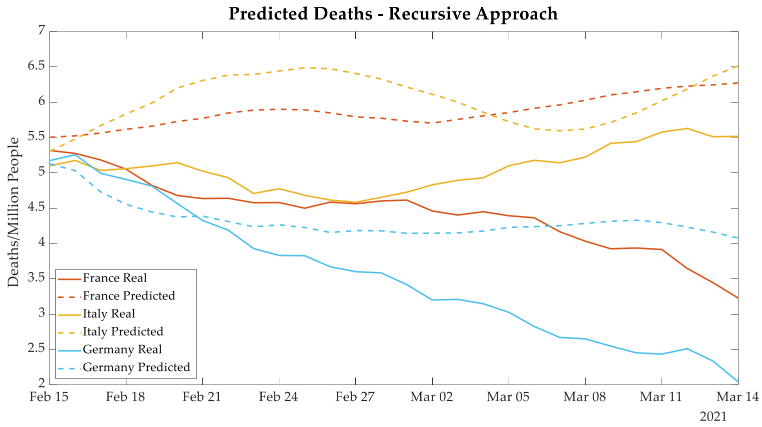

Figure A2. France, Italy, and Germany daily deaths - Recursive Approach

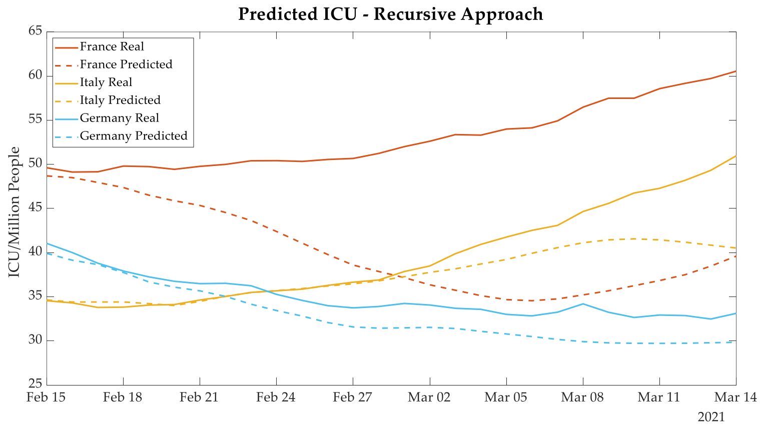

Figure A3. France, Italy, and Germany daily ICU patients - Recursive Approach

Appendix B

N approach's results of daily new cases, deaths, and ICU patients to France, Italy, and Germany.

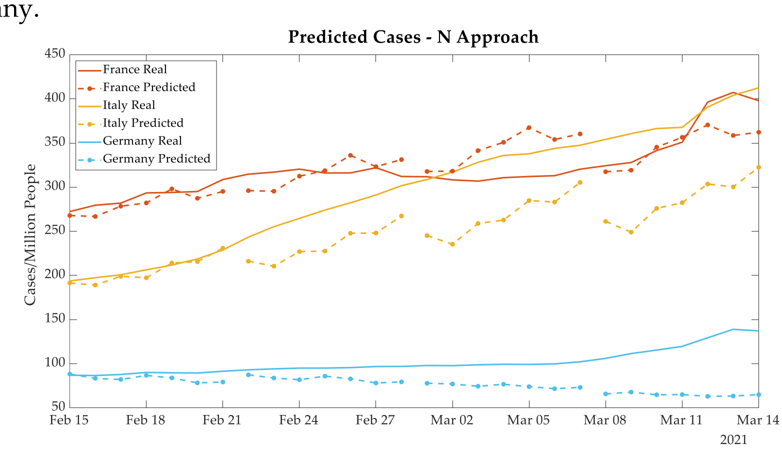

Figure B1. France, Italy, and Germany daily new cases - N Approach

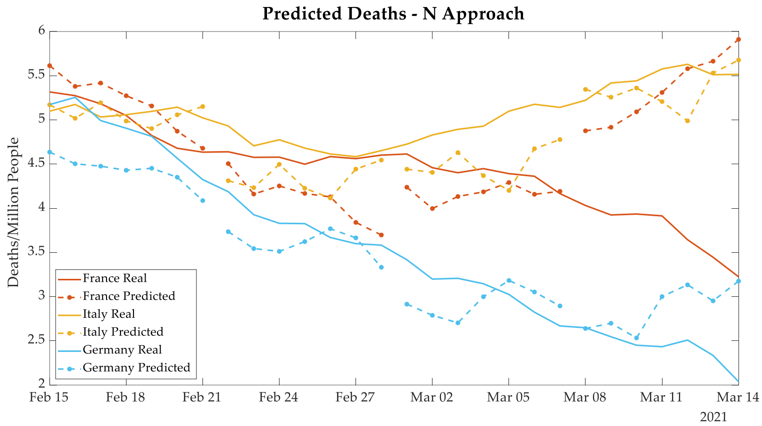

Figure B2. France, Italy, and Germany daily deaths - N Approach

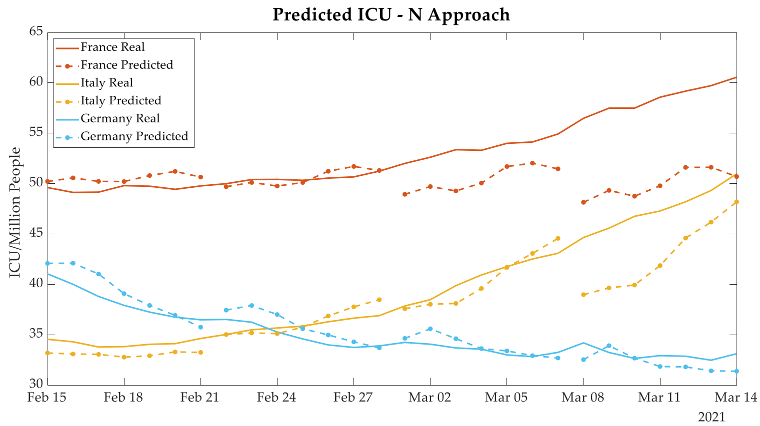

Figure B3. France, Italy, and Germany daily ICU patients - N Approach

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