Transfer function modelling of covid-19 pandemic in Nigeria

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The research work on transfer function modelling of COVID-19 pandemic in Nigeria purposely describes and adequately model the daily cases of COVID-19 from April to August 2020. The study yields a theoretical and empirical knowledge on the disease with univariate transfer function model and ARIMA (2, 1, 3) model. The fitted transfer function and ARIMA model is adequate for the study. The augmented Dick-Fuller (ADF) unit root test was used to test the stationarity of the series. The residual plot of the series shows adequacy of the fitted model. The study provides an estimate of the parameters via the transfer function which yields forecast value of 200 days of increasing daily cases. The study recommends the use of preventive measures stated here as non-adherence to increase the number of cases. An appropriate transfer function model was specified and its parameters were estimated. The choice of the best model is based on the model selection criteria application to the research. The univariate transfer function model is the best model for describing the COVID-19 pandemic in Nigeria. Evidently, from the forecast values, there exists a gradual increase of the cases of coronavirus in Nigeria as days go by. This is as a result of non-compliance to the preventive measures put in place by government and related agencies.

Keywords: ARIMA; COVID-19; time series forecasting; transfer function modeling

1. Introduction

The popular virus called coronavirus disease was discovered in the year 2019. The pandemic gripped the various countries of the world with great shock, hence overwhelming the health sector of most of the countries. The world health organisation known as WHO declared the virus that has engulfed the world as pandemic, which started in China in the city of Wuhan on December 9, 2019.It was reported that over seven million cases globally as at June 7, 2020: United States (over two million cases) and in Africa, South Africa (over fifty-four thousand cases) and Egypt (over thirty-eight thousand cases) bear the greater brunt. After the WHO declaration, the coronavirus preparedness group was constituted on January 31, 2020 in Nigeria. The WHO categorised Nigeria as one of the thirteen high risk African countries with respect to the spread of coronavirus. Nigeria is also among the vulnerable African nations given the weak state of the healthcare system (Marbort, 2020). In Africa, there exist communities or villages without healthcare facilities, apart from the scarcity of health workers to manage health cases (Amzat, 2011). This projection is that in Africa without effective measures to combat the pandemic, African could bear the final burden of the COVID-19 pandemic. The study tends to

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model the COVID-19 via the ARIMA and transfer function model and prediction made for the number of cases.

1.1 Transfer function modelling

Transfer function modelling models the interrelationship between input and output series. Given that X and Y denote a pair of observations at an interval of time such that an input X results to an output Y from a dynamic system. Note that both X and Y are continuous but are observed only at discrete times, in this case, transfer function models the interrelationship between X in an interval of time X_t and Y in an interval of time $Y_{t,}$. A transfer function model on COVID-19 pandemic in Nigeria models the daily cases of coronavirus in Nigeria at a 24-hourly interval, identifying the pattern, preparing the form of input and output series and specifying the model.

2. Literature Review

Nigeria is one of the 210 nations that was affected by the novel coronavirus disease. In Nigeria the first reported case was confirmed on 24th February 2020, in Lagos state by a 44 years old Italian citizen and presented himself for quarantine at a health facility on 26thFebruary 2020 (NCDC, 2020). It was reported that the first case, 216 people were identified as contacts to the index case and were followed up. Out of 216 persons, 45 travelled out of Nigeria and the rest of 176 contacts tested positive to the disease on 9thMarch 2020 (NCDC, 2020).

It is evident that in the face of continued COVID-19 community transmission, the health system may likely become overwhelmed with increased risk of Community Health Workers (CHWs) infection. Coronavirus disease is defined as a viral pneumonia with the symptoms such as sore throat, dry cough, fever, body pain, dyspnoea and diarrhoea etc. (Adhikari, 2020). SARS-Cov-2 is said to belong to the family of coronaviridae with important human and animal viruses which is permanent in circulation (Roussel *et al,* 2020; Peng *et al*, 2020). Nevertheless, COVID-19 affects citizens of all ages with greater severity. It is reportedly that mortality occurs high among the very aged humans (Lai *et al*, 2020). The infants exhibit small symptoms of COVID-19, this couldn't be identified for the reason (Brodin, 2020; Okyay, et al, 2020).

2.1 Mode of transmission

The COVID-19 is simply contacted through droplets which remain in the air for some periods, this transmission occurs via human interactions and contaminated fomites. The spread of COVID-19 to continents in African is mainly contributed by travellers (WHO, 2019). The daily cases of the disease are reportedly from European countries.

The inhabitants from Europe (especially from United Kingdom, France, Germany, Italy, Span and Netherlands) and the USA are duly stated as high-risk factor. The European nations are considered as people with high risk factors (Pullano *et al.*, 2020).

2.2 Mode of prevention

The awareness and the public campaign on social distancing by the public travellers, providing preventive measures highly recommended by health worker to reduce the spread of the virus (WHO, 2020).

There exists an increase of coronavirus cases in Nigeria. As at 14th April, 2020, over

5000 people exposed to the disease were tested and 343 persons tested positive to COVID-19, 10 deaths were recorded in Nigeria. The reported cases were travellers who had come back from other countries or people who had come in contact with the infected persons. More so, some of them are as a result of local transmission among people, especially from European countries (NCDC, 2020). Evidently, Nigeria is said to be among the thirteen countries in Africa with strong benefit on training of health officers and financial supports by WHO (Makoni, 2020).

As a new disease, the virus may continue to spread until majority of the citizens get infected and herd immunity is developed. More so, coronaviruses could stimulate population immunity in the pharynx of asymptomatic citizens that are not tested (Rousel et al, 2020).

2.3 Treatment

Adhikari and Meng (2020) states that there is no available therapeutic product which is effective for the cure of this virus called COVID-19. It is on record that numerous number of good medicines have being discovered to manage this virus, however many clinical trials have been on in solidarity with WHO.

2.4 Related literature

In predicting COVID-19 confirmed cases in Surabaya using autoregressive integrated moving average, bivariate and multivariate transfer function, (Saikhu et al, 2021) it was observed that ARIMA model has the worst training and testing performance because it cannot follow the actual data pattern and that bivariate transfer function has a better accuracy than ARIMA. Notwithstanding, multivariate transfer function was the best in modelling COVID-19 cases in Surbaya, multivariate transfer function model had training and testing performance at 0.478 and 0.108, respectively.

Antonio (2020) modelled the number of confirmed contagions (CON), death related to the disease (DTH) and the number of people recovered from it (REC) using simple transfer function to forecast the daily cases of COVID-19 in Spain. He discovered that forecasts are very precise for all forecasting periods and, only during the last forecasting horizon that was observed to be slightly over-predicted in the case of DTH.

Jasminal *et al.* (2020) in modeling the spread of SARS-CoV-2 by transfer function time series in different countries, the study countries were given a separate model with a state space on the stability of the analyzed system. The study reveals that the spread of the virus for each country has the same order of the adopted models for the study.

Livio (2020) observed that northern region in Italy will remain the most affected by the COVID-19, this was seen in a model-based method of the forecast on the total number of cases. The predictions from the model for 10 days was provided with a criterion based on the magnitude of the phenomenon. The study also reported the need for an intensive care unit.
Rediat (2020) applied the time series of autoregressive integrated moving average (ARIMA) modeling approach in projecting coronavirus (COVID-19) prevalence cases in East Africa Countries, mainly the Ethiopia, Djibouti, Sudan and Somalia, the result indicates increase in the number of cases in the study area.

Saswat et al. (2021) modeled the coronavirus disease via ARIMA model during the lockdown period and the period of free movement. The time series of interest shows the result of the number of cases and number of tests carried out during the said periods. The result of the forecast for the study is closely related with the actual cases currently.

Andres and Hector (2020) presented the analysis of COVID-19 spread which shows a different view for the whole world, via the 6 geographic regions (continents).The prediction of COVID19 on regions using ARIMA models and polynomial functions creates a good relationship between the countries of study which are in the same geographical area and predicts the advance of the virus.

Hassan et al. (2020) proposed a two-stage method of estimation that combines what is called the Extended Kalman Filter (EKF) in estimating the active and recovered cases of the modeled coronavirus disease. The method estimates the effective reproduction on the number of the virus. The new approach was based on the stochastic process called the discrete-time of the compartmental model which explains the transmission of the virus. The transfer function of the proposed model removes the short-term fluctuations of the time plots of the reported cases that tends to follow the Guassian distribution.

Resa et al. (2020) modeled the daily coronavirus cases in South Korea using Time series approach. The objective was to find the best model for the number of confirmed cases of coronavirus, number of recoveries and the number of recorded deaths. And this best model is one with the lowest RMSE and MAE. From their findings. GRNN model was discovered to be the best model. The results indicate the smoothing parameter for the best model as 0.000789, 0.0007, and 0.000945 for confirmed, recovered, and death data, with one autoregressive lag, respectively.

Linlin et al. (2019) used transfer function analysis to model the residential building cost in New Zealand by including the influences of house price and work volume. The time series model on the house price and work volume were used to explain and analyze the exogenous effects of the transfer function model. From this research, it was discovered that both ARIMA and transfer function models are reliable in this research. It further resolved that the simple models are not always reliable when additional information is available. The multivariate transfer function model proved to be more reliable in this research. This is because the bivariate transfer function model and the ARIMA model has 16 and 20 percent in the RMSE, respectively.

Abdulaziz, et al. (2020) stated that application of transfer function model showed that TF (3, 0, 1) showed the smallest value of model selection criteria, hence, the best and most appropriate model for the research as compared with other models.

Fang and Berlin (2014) used transfer function model in analyzing and forecasting students study achievements. The results show that although ARIMA model showed stability and accuracy, transfer function model showed more accuracy and will be a better model to predict students' academic performance in college exams.

3.0 Research Methodology

3.1 Model building

The Box and Jenkins (1976) approach of time series analysis terms to achieve and adopt the iterated modeling procedures below:

Model Specification: This method ensures that the variables are found stationary. By stationary, the process is differenced if necessary. The use of the graphs of autocorrelation and partial auto correlation functions is to decide the auto regressive or moving average component that is applied for further analysis.

Parameter Estimation: This approach involves using the adopted computational algorithm to derive the estimates that best fit the chosen time series (ARIMA) model for the study.

Model Checking (Residual Analysis): The approach is done by testing if the estimated model is adequate to the specifications of a stationary univariate process. In realistic nature, the residuals is stated to be independent of each other with constant mean and variance over time. The estimated model is refined when a fitted model is judged to be inadequate. The acceptance of the adequacy implies that the model has passed rigorous model checking, hence can be used for forecasting or policy simulation.

3.2 ARIMA model

The ARIMA (p, d, q) form is

$$\emptyset_p(B)(1-B)^d z_t = \theta_q(B)a_t \tag{1}$$

with the usual notation of p, q and d as the AR model order, MA model order and differencing order respectively,

$$\emptyset_p(B) = (1 - \emptyset_1 B - \emptyset_2 B^2 - \cdots - \emptyset_p B^p) \tag{2}$$

$$\theta_q(B) = (1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q) \tag{3}$$

The general ARIMA model of a seasonal pattern is written in the form ARIMA (p,d,q)

$$\emptyset_p(B)\emptyset_p(B^s)(1-B)^d(1-B^s)^D z_t = \theta_q(B)\emptyset Q(B^s)a_t \tag{4}$$

with s as seasonal period.

$$\emptyset_p(B^s) = \left(1 - \emptyset_1 B^s - \emptyset_1 B^{2s} - \cdots - \emptyset_p B^{ps}\right)$$

$$\emptyset_q(B^s) = (1 - \emptyset_1 B^s - \emptyset_1 B^{2s} - \cdots - \emptyset_Q B^{qs}) \tag{5}$$

Assumptions of ARIMA

i. The data must be stationary.
ii. The data must be univariate.

3.3 Single Input Transfer Function

Arumugam and Anithakumari (2013) stated the model for the transfer function model of the study as,

$$Z_t = c + \frac{\omega_s(B)}{\delta_r(B)} B^b X_t + N_t \tag{6}$$

$$\text{And } N_t = \frac{\theta(B)}{\emptyset(B)} \varepsilon_t \tag{7}$$

Putting equation (7) into equation (6) gives the transfer function model of a single input model as:

$$Z_t = c + \frac{\omega_s(B)}{\delta_r(B)} B^b X_t + \frac{\theta(B)}{\emptyset(B)} \varepsilon_t \tag{8}$$

Where $\omega_s(B) = \omega_0 + \omega_1(B) + \omega_1 B^2 + \cdots + \omega_s B^s$ (9)

$$\delta_r(B) = 1 + \delta_1(B) + \delta_2 B^2 + \cdots + \delta_s B^s \tag{10}$$

$$\theta(B) = (1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_1 B^q) \tag{11}$$

Z_t denotes the output series

C is a constant term

b denotes the delay

x_t is the input series

N_t is the error term

ε_t follows iid with mean zero and variance, σ_α^2

$\theta(B)$ is the Autoregressive Polynomial of the usual ARIMA model,

$\emptyset(B)$ is the moving average polynomial of the usual ARIMA model

ω_s is the numerator factor of transfer function

δ_r is the denominator factor of transfer function

3.4 Identification of a Transfer Function Order

Nwafor *et al.* (2018) states that the identification of a transfer function order is on the order of the polynomials.

Parameter Estimation: The parameter of these functions is estimated after all function of the model has been structured. The coefficients of the model also can be estimated by the method of least square on the assumption that the data set is stationary.

Transfer Function Order: It is worthy of note that the numerator order of the said transfer function specifies or states the previous value of the series from the selected independent series that is used to forecast the present values of the dependent time series variable. The order 0 includes the numerator components and the order 2 of numerators components of the model include order 2,1 and 0. The order 3 of denominator components of the model include orders 3, 2 and 1.

Assumptions of Transfer Function

According to Patricia (2016), assumptions of transfer functions are as follows:

i. Transfer functions are used for linear time invariant systems. Non-linear time varying systems need different analysis technique.
ii. Transfer function assume the system is initially at rest (zero initial conditions).

iii. Transfer function describe behaviour between single input and single output.

4. Result

The order of integration of the daily COVID-19 pandemic variable is inspected using the Augmented Dickey Fuller (ADF) units roots test, Dickey and Fuller (1969) in estimating and establishing that there exist long run relationship and to avert false result before performing this test, an informal inspection of the trends was established and difference done. The plot of the COVID-19 series in equation (12) indicates that the series are non- stationary at their levels. Hence, first difference indicates that the series was stationary.

In time series analysis, the estimation of forecast value is established when the adequacy of the model is valid. Table 4.5 indicates the forecast value of daily COVID-19 pandemic for the period of 200 days. The estimation procedure produced in table 4.2 of the ARIMA (2, 1, 3) model parameter and Table 4.3 is the univariate transfer function model of the COVID-19 pandemic from April to August 2020.

So, the model equation for the two estimated models on the COVID-19 pandemic are as follows:

The ARIMA, $Y_t = 1.097 - 0.869X_{t-1} - 0.957X_{t-2} - 0.261\varepsilon_{t-1} - 0.395\varepsilon_{t-2} + 0.658\varepsilon_{t-3}$ (12)
and the transfer function model is

$$Y_{covid-19} = 0.563 + \frac{(-0.814)\,(0.0334)\,(-0.0259)(0.0064)\,B^5 x_{t-1}}{(0.821)(0.559)} \tag{13}$$

$$Y_{covid-19} = 0.563 + \frac{4.5066 * 10^{-6} B^5 x_{t-1}}{0.4569}$$

$$Y_{covid-19} = 0.563 + 9.819 * 10^{-6} B^5 x_{t-1} \tag{14}$$

The two model equations (12) and (13) when compared with respect to the analysis yields that transfer function model performed better with the root mean square error of 0.753. See Table 4.3.

The study shows that the adequacy of the model was achieved. See the two plots of the residual ACF and PACF (Fig 4.2 and Fig 4.3) of transfer function and ARIMA (2, 1, 3) respectively. The study provides the forecast value of 200 days of COVID-19 pandemic from the best model (transfer function model) see Table 4.5 This study models the COVID-19 pandemic in Nigeria using transfer function model and ARIMA (2,1,3) model. The study ensures that the assumptions of ARIMA were satisfied. A step by step approach was employed in identification, estimation and checking adequacy of each model. The plot of residual autocorrelation function (ACF) and residual partial autocorrelation function (PACF) was used to check the adequacy of the model. Both plots can be seen to be declining geometrically. An appropriate transfer function model was specified and its parameters were estimated. The choice of the best model is based on the model selection criteria application to the research. Table 4.3 presents the normalized BIC (Bayesian information criteria) of 0.24, with root mean square error of 0.753 which best describes the COVID 19 data for Nigeria on the chosen model which is based on the minimum RMSE in the time series review. This model fit is seen as the one that best describes the COVID-19 data.

5. Conclusion

The average number of coronavirus cases recorded in Nigeria from April-August 2020 is 352 cases. The performance of ARIMA and transfer function model can be seen in their model fit as both have the values of R-squared at 0.81 and 0.627 respectively via the plot of the series. The univariate transfer function model is the best model for describing the COVID-19 pandemic in Nigeria. Evidently, from the forecast values, there exists a gradual increase of the cases of coronavirus in Nigeria over time. This is, as a result of non-compliance to the preventive measures put in place by government and related agencies. The increased number of coronavirus cases showed by the forecasts indicates that stricter measures be employed by relevant agencies to ensure compliance to the preventive measures.

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Appendix

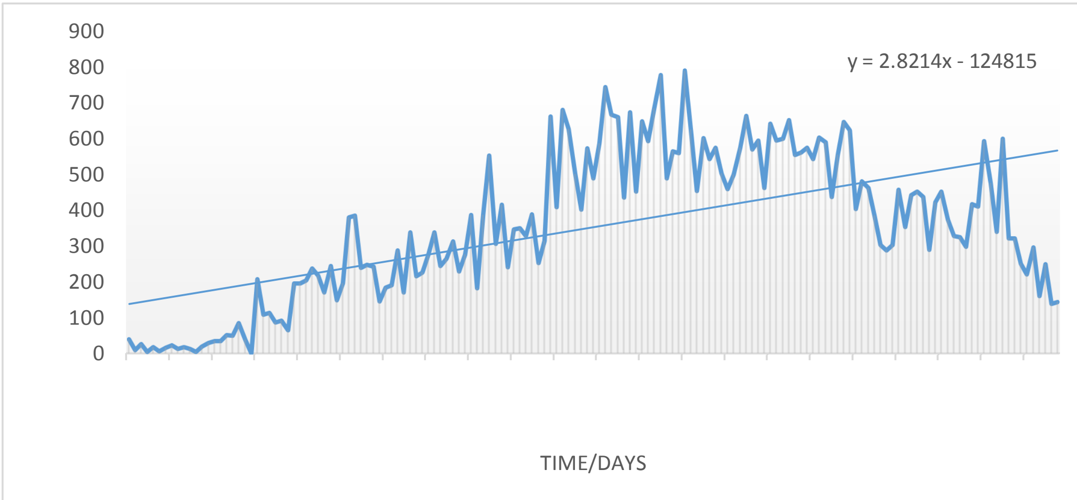

Figure 1: Original plot and least square estimation graph of COVID-19 from April to August 2021

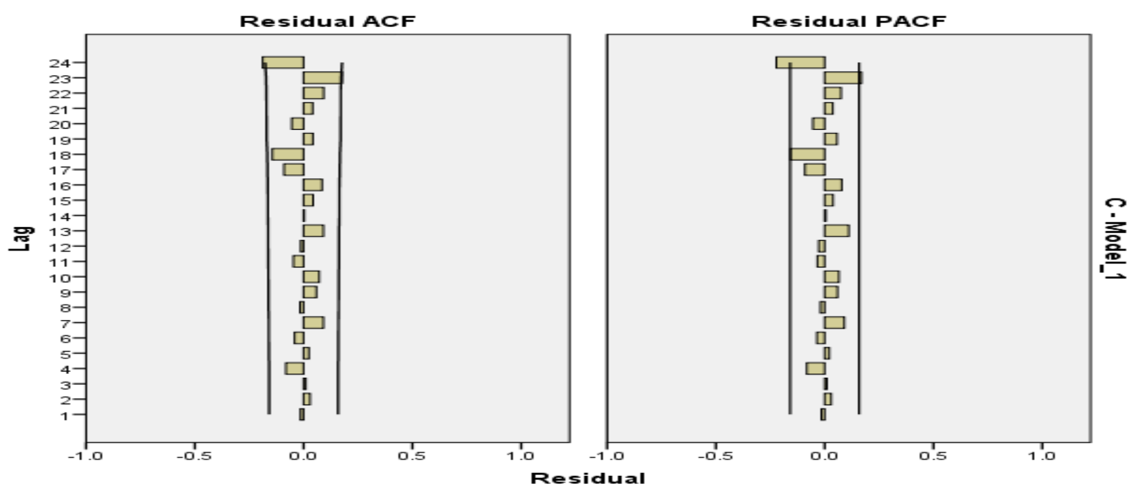

Figure 2: Display of Residual Partial Autocorrelation Function and Autocorrelation Function of COVID-19 from April to August 2020 by Transfer Function

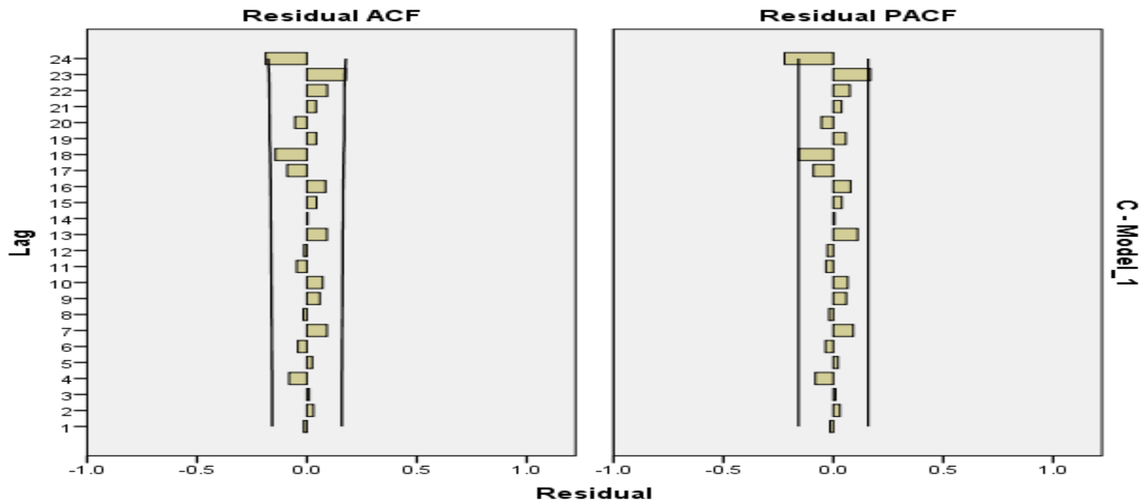

Figure 3: Display of Residual Partial Autocorrelation Function and Autocorrelation Function of COVID-19 from April to August 2020 by ARIMA

Table 1: Estimation of Transfer Function Modelling of COVID-19

COVID-19		Estimate	SE	t	Sig.
Constant		0.563	0.109	0.009	0.020
Delay		5			
Numerator	Lag 0	0.0334	0.004	0.201	0.002
	Lag 1	-0.0259	0.031	0.081	0.005
	Lag 2	0.0064	0.030	0.011	0.008
Difference		1			
Denominator	Lag 1	0.821	0.074	3.588	0.001
	Lag 2	0.559	0.041	-31.016	0.000
Numerator, Seasonal	Lag 1	-0.814	0.184	-5.633	0.000

Table 2: Estimation of ARIMA (2,1,3) Model Parameters

	Estimate			SE
COVID 19	Constant		1.097	0.006
	AR	Lag 1	-.869	0.058
		Lag 2	-.957	0.050
	Difference		1	
	MA	Lag 1	-.261	0.084
		Lag 2	-.395	0.003
		Lag 3	.658	0.004

TABLE 3: Model Fit Statistics forCOVID-19.

Fit Statistic	ARIMA (2, 1. 3) Statistics	TRANSFER FUNCTION Statistics
Stationary R-squared	.324	.534
R-squared	.801	.627

RMSE	93.996	.753
MAPE	33.370	22.959
MaxAPE	575.059	249.060
MAE	68.548	.388
MaxAE	323.011	2.491
Normalized BIC	9.285	.240

Table 4: Original Data

S/N	DATE	CASES
1	1-Apr	39
2	2-Apr	10
3	3-Apr	26
4	4-Apr	4
5	5-Apr	18
6	6-Apr	6
7	7-Apr	16
8	8-Apr	22
9	9-Apr	12
10	10-Apr	17
11	11-Apr	13
12	12-Apr	5
13	13-Apr	20
14	14-Apr	30
15	15-Apr	34
16	16-Apr	35
17	17-Apr	51
18	18-Apr	49
19	19-Apr	85
20	20-Apr	38
21	21-Apr	0
22	22-Apr	208
23	23-Apr	108
24	24-Apr	114
25	25-Apr	87
26	26-Apr	91
27	27-Apr	64
28	28-Apr	195
29	29-Apr	196
30	30-Apr	204
31	1-May	238
32	2-May	218
33	3-May	170
34	4-May	244
35	5-May	148
36	6-May	195
37	7-May	381
38	8-May	386
39	9-May	239
40	10-May	248
41	11-May	242
42	12-May	146
43	13-May	184
44	14-May	191
45	15-May	288
46	16-May	171
47	17-May	338
48	18-May	216
49	19-May	226
50	20-May	276
51	21-May	339
52	22-May	245
53	23-May	265
54	24-May	313
55	25-May	229
56	26-May	276
57	27-May	387
58	28-May	182
59	29-May	387
60	30-May	553
61	31-May	307
62	1-Jun	416
63	2-Jun	241
64	3-Jun	347
65	4-Jun	350
66	5-Jun	328
67	6-Jun	389
68	7-Jun	253
69	8-Jun	315
70	9-Jun	663
71	10-Jun	409
72	11-Jun	681
73	12-Jun	627
74	13-Jun	501
75	14-Jun	403
76	15-Jun	573
77	16-Jun	490
78	17-Jun	587
79	18-Jun	745
80	19-Jun	667
81	20-Jun	661
82	21-Jun	436
83	22-Jun	675
84	23-Jun	452
85	24-Jun	649
86	25-Jun	594
87	26-Jun	684
88	27-Jun	779
89	28-Jun	490
90	29-Jun	566
91	30-Jun	561
92	1-Jul	790
93	2-Jul	626
94	3-Jul	454
95	4-Jul	603
96	5-Jul	544
97	6-Jul	575
98	7-Jul	503
99	8-Jul	460
100	9-Jul	499
101	10-Jul	575
102	11-Jul	664
103	12-Jul	571
104	13-Jul	595
105	14-Jul	463
106	15-Jul	643
107	16-Jul	595
108	17-Jul	600
109	18-Jul	653

110	19-Jul	556
111	20-Jul	562
112	21-Jul	576
113	22-Jul	543
114	23-Jul	604
115	24-Jul	591
116	25-Jul	438
117	26-Jul	555
118	27-Jul	648
119	28-Jul	624
120	29-Jul	404
121	30-Jul	481
122	31-Jul	462
123	1-Aug	386
124	2-Aug	304
125	3-Aug	288
126	4-Aug	304
127	5-Aug	457
128	6-Aug	354
129	7-Aug	443
130	8-Aug	453
131	9-Aug	437
132	10-Aug	290
133	11-Aug	423
134	12-Aug	453
135	13-Aug	373
136	14-Aug	329
137	15-Aug	325
138	16-Aug	298
139	17-Aug	417
140	18-Aug	410
141	19-Aug	593
142	20-Aug	476
143	21-Aug	340
144	22-Aug	601
145	23-Aug	322
146	24-Aug	321
147	25-Aug	252
148	26-Aug	221
149	27-Aug	296
150	28-Aug	160
151	29-Aug	250
152	30-Aug	138
153	31-Aug	143

Table 4.5 forecast

DAYS	Forecast
154	187
155	183
156	202
157	193
158	185
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160	198
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353	408