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# Stochastic Models for Coronavirus Cases in Nigeria

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**Abstract**— The stochastic models over the years have been used for business, stock markets transportation and many different areas. As result the prediction of any ideas based on these models needs to be efficient. Now, the infection of corona virus has been a battling task for the human race as well as the Nigerian government. In this paper we seek to apply stochastic models to determine the prevalence rate of the virus and to predict the future re occurrence of the disease. The proposed models is driven by a Stochastic Discrete Time and Continuous Time Markov Time model of SIR (Susceptible, Infected and Recovered) model. When fitted to COVID-19 data it generates a typical observed features. In particular, it captures the behavior of this epidemic. Fundamental probabilistic predictions, model parameters were deduced from the models used. This form as a basis for managing successfully

**Index Terms**—CTMC, Infected, Markov model, Recovery rate, Recovered, and Reproduction number ($R_0$) transmission rate and Susceptible.

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## 1.0 INTRODUCTION

THE highly infectious disease called coronavirus disease (COVID-19) which belongs to a family of virus [1] was first discovered in Wuhan city Hebei province of china in December, 2019 [2]. World health organization (WHO) branded the term COVID-19, to depict how corona virus affects the lower respiratory tract of patients with pneumonia in Wuhan China [3-5]. Presently a reference name for the virus is severe acute respiratory syndrome coronavirus 2(SARS-COV-2) [5]. Coronavirus cause ailments from common cold to severe diseases such as MERS an SARS [8, 9]. When people are infected with the COVID-19 virus, they contract mild to moderate respiratory disorder and may recuperate without the need for special treatment. The elderly and those with terminal illness such as cancer, are prone to becoming severely sick. The full range of the clinical symptoms is not totally clear, but it can lead to the death of the infected [3]. Symptoms that are commonly reported includes fever, cough, aches, tiredness, pneumonia, and complicated dysuria. Less common symptoms are headaches diarrhea, hemoptysis runny nose, and phlegm-

producing cough [10]. Reports indicates that patients with common in middle-aged and elderly patients who already suffer from disease as hypertension, coronary heart disease, tumor diabetes, cirrhosis and Parkinson's disease [12]. Incubation period of COVID-19 infection is approximately 6 days.

The virus spreads predominantly when an infected person coughs or sneezes and releases droplets of saliva or discharge from the se in the process. This makes it crucial to adopt respiratory etiquette (for example. Coughing into a flexed elbow) [13]. To control the spread of this virus, china banned the movement of 57 million people in Wuhan and 15 surrounding cities. The tourist cities were closed, celebrations of the Chinese New Year were cancelled to avoid the transmission of the virus [14]. Same was adopted was adopted in Nigeria with the closure of churches, mosques, social gathering and celebration. [14], further stressed that there are some studies that work on discovering the cause that lead to the transmission. As explained by the world health organization (WHO), infection among individuals including the incubation period for the disease is five or more

days. The WHO has decided that antibiotics should not be used in the prevention or treatment of this virus. As result, patients receive care to relive symptom. Although there are some medications and antibiotics that reduce the severity of the symptoms of this virus, there is no current treatment to prevent the virus [15].

On 27th February 2020, the Nigerian government confirmed its first ever case of COVID-19 following an Italian citizen who works in Nigeria and returned from Milan, Italy to Lagos. The government had started making preparations since it knew that ultimately the virus would have a huge economic impact once it lands in other part of Nigeria. They were able to achieve a near success rate by taking some fiscal and monetary measures to deal with the economic conditions prevailing in the country.

Containing COVID 19 should be the current target, since the closure of institutions and public places and on travels and trades cannot be upheld indeterminately [16]. Individual case containment might not be possible in the long run and there might not be need to move from place to another, thereby balancing the costs and benefit of public health measures. Since the beginning of COVID-19 in china, the economy has been in chaos globally [6]. Reasons being that china has a direct correlation with most economies in the world, they rely on it directly or indirectly [7].

Various researchers [17], [18] and [19] have applied mathematical modelling to gain meaningful insight to study the spread of infectious disease such as malaria, zika virus and influenza, among others. [20], have generated mathematical and statistical model considering different variables. [21], modelled the Economic impact of coronavirus using a Discrete – time Markov chain while [22],

predicted the corona virus in India using Markov models. This research intends to employ stochastic models to coronavirus cases in Nigeria, ascertain the impact of the variable: confirmed, discharged and death cases and to forecast with the selected models.

## 2.0 METHODOLOGY

[23] describes the stochastic process as family of random variable X, where it is a parameter running over a suitable index at T, and can be conveniently written as X(t) instead of $X_t$. stochastic process are distinguished by their state or range of possible values for the random variables $X_t$ by their index set T and by the dependence relations among the random variables X. stochastic models reflects on the daily cases and important predictions or implications about the spread can be determined. In this research work, state spaces to be considered are confirmed cases (susceptible) discharged cases (infected) and deaths (Recovered).

### 2.1 Discrete Time Markov Chain

[24], defines discrete Markov chain as a sequence of random variable $X_1, X_2, \dots, X_n$ characterized by the markov property which states that the distribution of the forthcoming state $X_{n+1}$ depends only on the current state $X_n$ and doesn't depend on the previous state $X_{n-1}, X_{n-2}, \dots, X_1$.

### 2.1.1 Markov chain modelling

Is a stochastic model that describes a sequence of all probable events that gives the probability of every event depending only on a given state attained in the proceeding event [24]. All Markov chain models are based on the transitional probability matrices of various time steps.

Mathematically, this means that the probability of observed state I at time t transitioning to state j at time t+1 is denoted as

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$$P_{ij}(t) = \Pr[S(t+1) = j \,/ S(t) = i]$$

(1)

where $S(t)$ is the observed state at time t.

In order to calculate the Markov transitional probabilities the cases are divided into 3 states according to the months. In general the number of states at each time instant be assumed as n. Hence there will be $nxn$ transitions between three successive times (months) instances. It is then possible to find the number of transition probabilities $P_{ij}$ from state at time t to another state at time t+1 and accordingly, the following transition probability matrix $P_{ij} = P_{t,t+1}$ can be prepared from observed case. The structure of the transition probability Matrix would be

$$P_{t,t+1} = \begin{bmatrix} P_{11} & P_{12} \dots & P_{1n} \\ P_{21} & P_{22} \dots & P_{2n} \\ P_{nI} & P_{n2} \dots & P_{nn} \end{bmatrix}$$

(2)

And following the estimate by [25]

$$P_{ij} = \frac{f_{ij}}{\Sigma f_{ij}} \quad i,j = 1,2,\dots c$$

(3)

Where $f_{ij}$ = historical frequency of transition from state $i$ to state $j$ and

c = maximum number of state. Any state probability varies between zero and one, notationally $0 \le P_{ij} \le 1$ and $\sum_{j=1}^{n} P_{ij} = 1$

## 2.2 Continuous Time Markov Chain

[26], says continuous time Markov chains is a stochastic process with state space $i = 0,1,2,\dots$ and $t \ge 0 \,\{X(t), t \ge 0\}$.

$$P(X(t) = \{x/\mathrm{X}(t_1) = x_1 X(t_2) = x_2, \dots X(t_n) = x_n\}$$

$$= P\{X(t) = x/X(t_n) = x \ for \ all \quad 0 < t_1 < t_2 < \dots < t_n < t$$

(4)

Models for formulation of continuous time Markov chains and stochastic differential equations are the SIR (Susceptible, Infected and Recoveries [deaths]) epidemic model.

Stochastic modelling of epidemic is important when the number of infectious patients is small or when the rate in transmissions, recovery, deaths, births, or the environment impacts the epidemic outcomes [27]. The variability associated with individual dynamics such as transmission recovery birth or deaths is often referred to as a demographic variability. While if it is associated with environment related to terrestrial or aquatic settings it is referred to as environmental variability. Modelling infectious diseases, waterborne diseases (e.g Ebola, avarian influenza, malaria and cholera) environmental variability is important. [15], [16], [17].

In this research work, emphasis is on demographic variables in time space. In the continuous time Markov models (CTMC) and stochastic differential equations (SDE), the time variable is continuous, $t \in [0, \infty]$ but the state variables are either discrete (CTMC) or continuous (SDE). The stochastic CTMC epidemic model of SIR is applied for the COVID data in Nigeria.

### 2.2.1 SIR Deterministic Epidemic Model

The SIR accurately represents how an infection would spread through a population because it takes into consideration that some people will recover from the disease and no longer be susceptible (confirmed). This model assume that people who recover from the infection becomes immune and cannot become infected the second time [28]

In the SIR model, the population is divided into three types

(i) Susceptible(S) [confirmed but may not be infected]

(ii) Infected(I) [confirmed but infected and discharged]

(iii) Recovered (R) [death]

$[\![S]\!] \to [\![I]\!] \to [\![R]\!]$

$S(t)$
$= S - number\ of\ susceptible\ individual\ at\ time\ t$

$I(t)$
$= I - number\ of\ infected\ individuals\ at\ time\ t$

$R(t) = R - number\ of\ deaths\ at\ time\ t$

$S(t) + I(t) + R(t) = N$
**(5)**

Where
$S(t) = \frac{S(t)}{N} =$
$the\ proportion\ of\ susceptible\ individuals\ at\ time\ t$

$I(t) = \frac{I(t)}{N} =$
$the\ proportion of\ infected\ individuals\ at\ time\ t$

$R(t) = \frac{R(t)}{N} = the\ proportion\ of\ death\ at\ time\ t$

The model for the SIR is written as

$\frac{\partial s}{\partial t} = -\beta si$
**(6)**

$\frac{\partial i}{\partial t} = \beta si - \gamma i$
**(7)**

$\frac{\partial r}{\partial t} = \gamma i$
**(8)**

Where beta (β) is called the transmission rate derived by [29] and represented as $\frac{-\log\left(1 - \frac{I_N}{I}\right)}{T * S/N}$
**(9)**

and gamma (γ) is called the recovery rate which is the number of recovered divided by the number of infected.

**The Reproduction Number $R_0$**

This measures how many people an infected individual will transient the disease to before they recover and it is given by the symbol $R_0$[28]. The magnitude of $R_0$ not only indicate there spread of

how a disease will spread, but whether it will not spread at all. If it is the case that

$R_0 > 0$, then the infection will spread throughout the population, but if

$R_0 < 1$, then the infection will not be able to take hold and will eventually die out.

In the SIR model, the basic reproduction number $R_0$ can be calculated using the ratio of the transmission rate (β) to recovery rate (γ).

$R_0 = \frac{\beta}{\gamma}$
**(10)**

## 3.0 RESULTS AND DATA ANALYSIS

### 3.1    PRESENTATION OF DATA

This study was conducted on the basis of confirmed, discharged and deaths cases of COVID 19 cases, collected from the official website of the Nigerian Centre for Disease Control (NCDC) from 30th march 2020 to 16 October 2020.
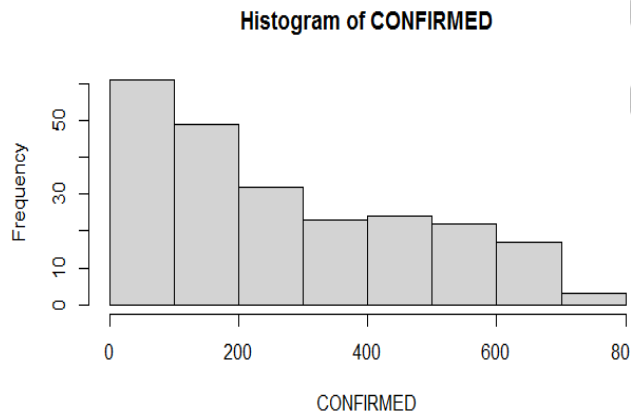
**Table 1: New cases of COVID 19 in Nigeria**

| S/N | DATE | CONFIRMED | DISCHARGED | DEATHS |
|---|---|---|---|---|
| 1 | 29-Feb | 1 | 0 | 0 |
| 2 | 1-Mar | 0 | 0 | 0 |
| 3 | 2-Mar | 0 | 0 | 0 |
| 4 | 3-Mar | 0 | 0 | 0 |
| 5 | 4-Mar | 0 | 0 | 0 |
| 6 | 5-Mar | 0 | 0 | 0 |
| 7 | 6-Mar | 0 | 0 | 0 |
| … | …. | … | … | … |
| 229 | 14-Oct | 179 | 137 | 0 |
| 230 | 15-Oct | 148 | 51 | 0 |
| 231 | 16-Oct | 212 | 110 | 3 |

**Table 2: Descriptive statistics on COVID 19 data**

| Statistics | Confirmed | Discharged | Deaths |
|---|---|---|---|
| N | 231 | 231 | 231 |
| Mean | 264.78 | 179.32 | 492 |
| Standard deviation | 213.960 | 284.480 | 5.329 |
| Skewness | 0.511 | 7.443 | 1.406 |
| Kurtosis | -0.867 | 78.228 | 2.297 |
| Maximum | 790 | 3442 | 31 |
| 50th percentile(median) | 216.00 | 125.00 | 3.00 |
| 1st quartile | 91 | 16.5 | 0.5 |
| 3rd quartile | 436.5 | 247.5 | 7.5 |
| Coefficient of Variation | 80.8% | 158.6% | 1.08% |

**b. Discharged cases**



Histogram of DISCHARGED

**c. Death**



Histogram of DEATHS

**a. Confirmed cases**



Histogram of CONFIRMED
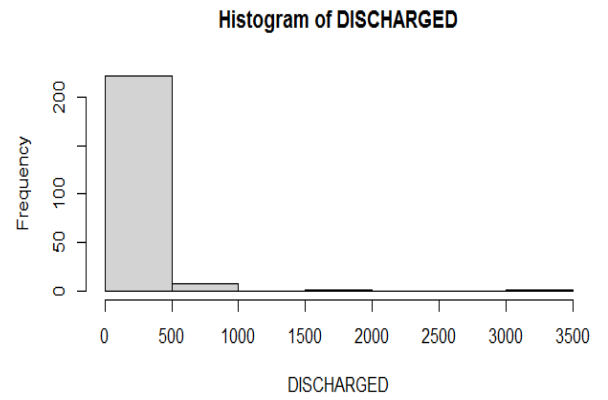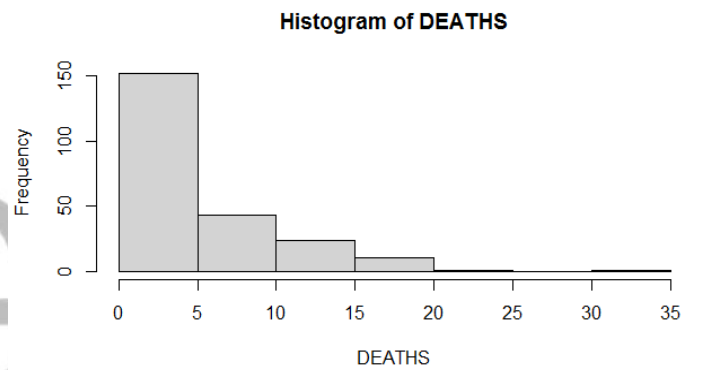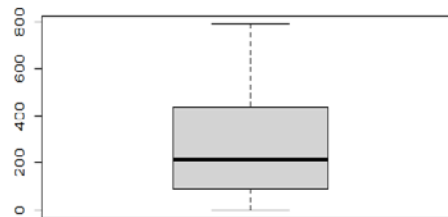
**e. Confirmed cases**
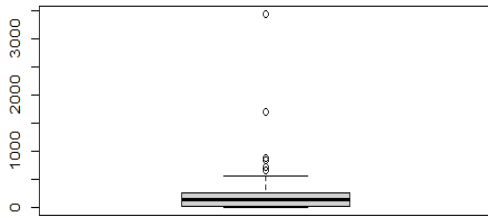
**f. Discharged cases**
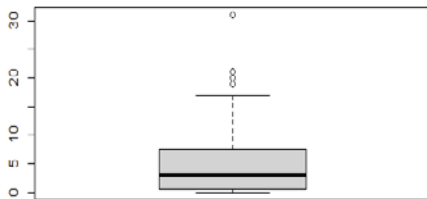


**e. Deaths**



**g. Confirmed cases**



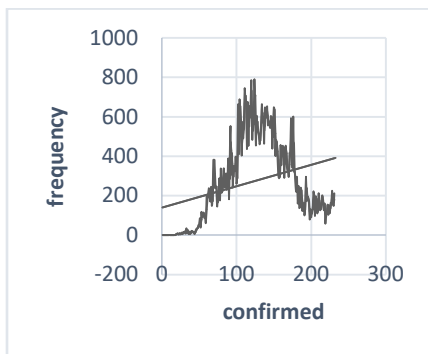**h. Discharged cases**
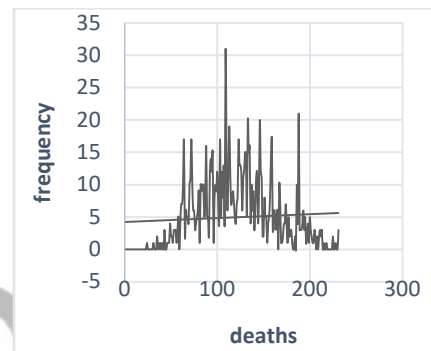


**i.Deaths**



**Figure 1:** Exploratory data analysis plots.

**Preliminary analysis**

The exploratory data analysis (EDA) are carried out in this section using descriptive statistics and various charts, including time plots to show some hidden features in the datasets. **Table 2** displays part of the data collected on COVID-19. **Figure 4** are plots that show hidden features of the datasets. Figures **a, b** and **c** are histograms, **e, f** and **g** are boxplots, while **h, i** and **j** are cumulative plots (indicating its trends) of new COVID-19 cases, new COVID-19 induced deaths and new COVID-19 recovered cases respectively.

## 3.2 APPLICATION OF MARKOV CHAIN TO COVID 19 DATA

The probability transition matrix P describes the Markov chain representing the three states of the three states of corona virus (COVID 19) infection was obtained from **2**

$$P = \begin{bmatrix} 0.0313 & 0.0079 & 0.2951 \\ 0.6736 & 0.4665 & 0.5257 \\ 0 & 0 & 1 \end{bmatrix}$$

**(11)**

**Table 3: Frequency Distribution of the corona virus infections according to states**

The transition chances illustrates that, there is 3.13% chance

in the first level (confirmed level) of corona if N=103724. In the second stage (Discharged) 67% chances are there. Therefore Corona recovered possibilities in Nigeria as on 16th October, 2020 is 67%. In the third stage (Death level) 29.5% of probabilities for the given statistics if N=103724.

The present Markov chain model a non –recurrent

| starting | state | Two days | Four days | Eight days | Sixteen days | Twenty four |
|---|---|---|---|---|---|---|
| From Initial | susceptible | 0.0063 | 0.0014 | 0.0001 | 0.0020 | 0.0054 |
| From time | infected | 0.3353 | 0.0769 | 0.0040 | 0.1105 | 0.3031 |

process that through a number of transient states, eventually leads to an absorbing states (deaths) of no return. Since the state space contains both transient and recurring (absorbing) states, there is no point in obtaining the steady state solution. Instead, we obtain

(i) The long run probabilities of dying as well

(ii) The expected times to die after contracting the virus, both of starting at states 1 and 2

In order to achieve this, we obtain from P the sub matrix of all the transient states by deleting the row and column corresponding to the absorbing state.

The remaining matrix "Q" of the transient state

$Q = \begin{bmatrix} 0.0313 & 0.6736 \\ 0.0079 & 0.4665 \end{bmatrix}$ We subtract matrix Q from the identity matrix, yielding $(I - Q)$, and invert this latter one

**Matrix inverse $(I - Q)^{-1}$ of transient states confirmed (susceptible) and discharged (infected)**

$\begin{bmatrix} 1.0431 & 1.3169 \\ 0.0155 & 1.8939 \end{bmatrix}$ This matrix gives the long run average number of visits to each states of the said column matrix, when starting from the states of the matrix rows. For example the average number of days a susceptible individual becomes infected is 1.8 days (approximately 2days). From the matrix the expected times to die after contracting the virus is averagely: 1.0431+1.3169=2.36days.

We now calculate the probabilities of a patient dying, starting from any of the transient state. We calculate the probabilities for a horizon of two, four, eight or sixteen days (considering that the death has occurred after said person started from the considered transient state)

| States | Status | Frequency |
|---|---|---|
| 1 | Confirmed(susceptible) | 61165 |
| 2 | Discharged(infected) | 41423 |
| 3 | Deaths(Recovered | 1136 |
| | Total | 103724 |

We can see that the probability of dying in twenty four days or less after becoming infected is 30%, which is relatively low.

**Table 4: Probabilities of patients dying starting from any of the transient state**

## 3.3 APPLICATION OF CONTINUOUS TIME MARKOV MODEL (CTMC) TO COVID 19 DATA

According to [29], in order to model the continuous time Markov chain, the Gillespie stochastic simulation algorithm was used to incorporate available data such as the susceptible, infected and recovered at a predefined time points.

The R package **SimInf** helps us to conduct data driven modeling in a realistic large scale disease spread simulations.

**Estimation of Parameters**

From equation (**9**), $\beta(beta) = 0.0011$,

And $\gamma(gamma) = \frac{number\ of\ recovered\ (death)}{number\ of\ infected\ (dischaged)} = 0.027$

From equation (**10**), $R_0 = \frac{\beta}{\gamma} = 0.041$

The results of the simulations are as follows, assuming the N = 100000, S = 62000, I = 37000 and R = 1000(these values are close to the estimated values in **table 3**)

**Table 5: Simulation results of the unit per day over 300 days**

Compartments

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|---|---|---|---|---|---|---|
| S | 60909 | 61053 | 61092 | 61218 | 61239 | 61992 |
| I | 9 | 143 | 1077 | 6598 | 7427 | 36163 |
| R | 1867 | 31334 | 37835 | 32184 | 38804 | 39064 |

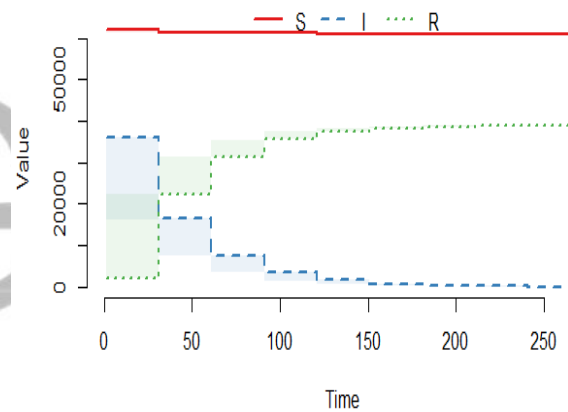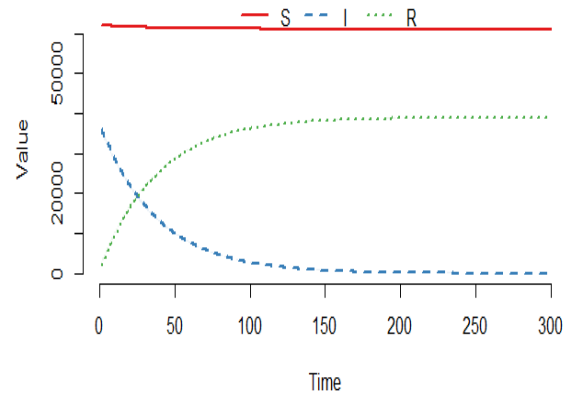| | Node | time | S | I | R |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 61972 | 36060 | 1968 |
| 2 | 1 | 2 | 61952 | 35115 | 2933 |
| 3 | 1 | 3 | 61928 | 34238 | 3834 |
| 4 | 1 | 4 | 61906 | 33379 | 4715 |
| 5 | 1 | 5 | 61888 | 32509 | 5603 |
| 6 | 1 | 6 | 61857 | 31749 | 6394 |





**Figure 2**: Output from the stochastic SIR model in 100000 nodes starting with 62000 susceptible, 37000 infected and 1000 recovered individuals in each node $(\beta = 0.0011, \gamma = 0.027)$. **Left:** We assume the unit one day and simulate over 300 days. **Right:** The unit of time is one day and simulate over 300 days returning results every 30th day.

**Table 6: Simulation results of the unit per day over 300 days returning results every 30th day**

Compartments

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|---|---|---|---|---|---|---|
| S | 60909 | 61053 | 61092 | 61218 | 61239 | 61992 |
| I | 9 | 143 | 1077 | 6598 | 7427 | 36163 |
| R | 1867 | 31334 | 37835 | 32184 | 38804 | 39064 |

| Node | time | S | I | R |
|---|---|---|---|---|
| 1 | 1 | 1 | 61972 | 36060 | 1968 |
| 2 | 1 | 31 | 61483 | 16404 | 22113 |
| 3 | 1 | 61 | 61259 | 7464 | 31277 |
| 4 | 1 | 91 | 61153 | 3318 | 35529 |
| 5 | 1 | 121 | 61083 | 1560 | 37357 |
| 6 | 1 | 151 | 61062 | 683 | 38255 |

As the proportion of susceptible (confirmed) [the red line] individuals dwindled a little on day 49, and 110 (i.e on the 17 April, 2020 and 17 June, 2020) then remains constant over time (i.e individuals confirmed but not really infected only varies very slightly), deaths (recovered) [the blue line] individuals decreases, while the infected (discharged) individuals increases over time, these lines represents how the trends of susceptible, infected and recovered individuals changes over time. In figure 2 (**left)** this means that the entire population of susceptible (confirmed cases) individuals in Nigeria will remain constant over time, and possibly move to being infected (discharged) and eventually low chances of death.

The same is applicable to the figure 2(**right)** the trends over 300 days returning on every 30th day helps to understand that the susceptible experienced an obvious decrease on day 110 and becomes constant or varies slightly in the month of June, July, August, September and October, 2020. Infected individuals (patient infected and discharged from the hospital) reduces from 29 march (31st day), 29 April (61st day), 31 May (91st day), and 27 July 2020 (121st day), and so on, and becomes more frequent and steady over the next few these days. This same is applicable to the recovered cases.

## 4.0 DISCUSSION AND RESULTS

### 4.1 Prediction and forecasting with the selected models

We apply a 3 state Markov Model to study the dynamics of the COVID 19 infection and the impact of containment strategies. The estimated long run stable transition probability helps us to understand the course of each state transition. Together with the estimated life expectancy over time and the long run probabilities of dying or being in the death state i.e estimated fatality rate for COVID-19 in Nigeria is about 30%. If not contained, it will be transmitted to the entire population and most people who are vulnerable become sick.

From **table 4** the probability of dying starting from the confirmed /infected state over a period of days though fluctuating will become minimal in the future

The CTMC explains the stochastic behavior of the epidemic and it revealed a fundamental probabilistic properties of the dynamics of the model by giving an important insights to each case (Susceptible, Infected and Recovered) **table 5** and **6** explains the results over the total population with an initial 62000 susceptible (confirmed) 37000 infected (discharged) and 1000 recovered (deaths) which are equivalent to the data collected up on till 6th October 2020.

**Figure 2** demonstrates that overtime, the constant confirmed (susceptible cases in Nigeria, and the rate of discharged case (infected) is reducing at a steady rate tending toward zero. The virus will eventually die out and we will come to conclusion that not all susceptible are infected with the disease.

The reproduction rate ($R_0$) being less than zero still affirms to the conclusion made on the models above that the infection will not be able to take hold of the population and will eventually die out

### 4.2 Economic implications of this findings

As a result of the wide lockdown , there have been concerns around the overall economic activity in sectors likes retails, banks, real estate, industries', Education but to mention a few. Based the predictions of this research work there is no cause for alarm as the economy of Nigeria is gradually getting back on its feet, though we still have confirmed/susceptible cases, as said earlier most of the these cases might not be COVID-19 related and It could be due to other ailments.

### 4.3 Suggestions/Recommendations

In this work, we have proposed and analyzed a stochastic model to consider the impact and control the transmission dynamics of COVID-19 in the population of interest. In the course of modeling, it was assumed that susceptible/confirmed individuals contract the infection through direct contact with infected persons, as well as indirectly through the presence of coronavirus in the environment. First, the Discrete Markov model was qualitatively analyzed, the Continuous Time Markov Model to study its spread were determined and basic reproduction number $R_0$ in the absence of hygiene was obtained. Furthermore, the model parameters for the model simulation were obtained. This study reveals that the probability of getting infected is as low as 29%. Based on the results and findings of this study, the following recommendations are made

a. The most sensitive parameters that increases the basic reproduction number $R_0$ is lack of restriction. The restriction in this context could be total or partial depending on the severity of the spread of the disease.

b. In view of recommendation (1) above, we are also suggesting that testing and isolation centers should be made available and fully functional at the borders in particular, the airports. This is to ensure that only immigrants who test negative or who had been observed to be free from symptoms of the disease at the isolation center, within the disease incubation period (for COVID-19, a maximum of 14 days is recommended globally) would be allowed into the country.

c. The result of the Markov chain model states that the probability of being infected is above average when an individual comes in contact with an infected person, which is relatively high. Thus, the stay at home policy, social distancing, and hand washing with alcohol- based sanitizer should be strictly maintained. Since the virus cannot spread without a medium, then the best policy is the stay at home and when the need arises, to go out always put on your nose mask.

d. The present study revealed that promoting good hygiene via education/creating awareness (information) can help induce attitudinal change among the people, thereby influencing individuals to emulate good and healthy habits to protect themselves against the disease.

Information degenerate over time and can be attributed to factors, such as human lackadaisical attitude, and lack of resources, among other reasons. Thus, education campaign on the disease transmission and how it could be prevented must be sustained through social media, TV, Radio, Talk shows e.t.c. If these recommendations are taken seriously by all stakeholders, then, we might be on the right path to flattening the curve. Conclusively, as efforts to effectively combat COVID-19, further analysis can be done to improve the present work by looking into other types of stochastic models (Ito's differential equations (SDE), hidden Markov models, to determine extent its spreads would get to in the future. Thus, it is also essential to consider a stochastic model that will take into account social distancing, isolation and budget to propagate information to warn people on how to maintain good sanitation to curtail the spread of the disease.

All these shall form the foundation for another research work.

## ACKNOWLEDGMENT

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