MODELING OF COVID-19 MAJOR OUTBREAK WAVE THROUGH STATISTICAL SOFTWARE: QUANTITATIVE RISK EVALUATION AND DESCRIPTION ANALYSIS

COVID-19 büyük salgın dalgasının istatistiksel yazılım yoluyla modellenmesi: niceliksel risk değerlendirmesi ve tanımlama analizi

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Abstract

The recent COVID-19 global pandemic has stimulated a search for an effective hazard index based on public health criteria. The study herein is discussing quantitative techniques for health hazard estimation and analysis of risk through selected epidemic cases in an island country. The case investigation comprises a combination of unique statistical process methodologies of descriptive analysis, control charts, Pareto charts, data modeling, in addition to the visual monitoring of cases and death patterns chronologically. Trending charts showed that the outbreak attack takes the form of two waves: the first major and sharp peak followed by a low noise level before another minor relapse occurs. The morbidity rate was low with the contribution of illness from the total country population of approximately 0.02%. While the dispersion of the number of evolved cases of infection followed Gaussian distribution in the major wave, the mortality number failed to show signs of normal spreading of data indicated by significant drifting of skewness and kurtosis values from the normal distribution. However, the overall dispersion of the individual counts of cases and deaths during the period of the study demonstrated truncated distribution limited by the lower value of zero. Mathematical description of the major wave as cumulative cases and deaths followed the Richards model with good regression (r>0.996). The established analysis serves as a milestone for swift quantitative assessment of the pandemic impact based on mortality/morbidity using simple inexpensive statistical programs which would be valuable in the medical field for the study of outbreaks.

Keywords: Control Chart, COVID-19, Morbidity/Mortality, New Zealand, Pareto diagram, Richard Model

Özet

COVID-19 küresel salgını, son zamanlarda halk sağlığı kriterlerine dayalı etkili bir tehlike indeksi arayışını teşvik etti. Buradaki çalışma, bir ada ülkesindeki seçilmiş salgın vakaları üzerinden sağlık tehlikesi tahmini ve risk analizi için kantitatif teknikleri tartışmaktadır. Vaka araştırması, vakaların ve ölüm paternlerinin kronolojik şekilde görsel olarak izlenmesine ek olarak tanımlayıcı analiz, kontrol grafikleri, Pareto grafikleri, veri modeleme gibi istatistiksel süreç metodolojilerinin bir kombinasyonunu içerir. Trend grafikleri, salgın atağının iki dalga şeklinde olduğunu gösterdi: ilk büyük ve keskin tepe noktası, ardından başka bir minor relaps meydana gelmeden önce düşük seviyeli bir dalga. Morbidite oranı, hastalığın toplam ülke nüfusunun yaklaşık %0,02'lik katkısıyla düşüktü. Dönüştürülmüş enfeksiyon vakaları sayısının dağılımı, ana dalgada Gauss dağılımını takip ederken ölüm sayısı, normal dağılımdan çarpıklık ve basıklık değerlerinin önemli ölçüde kaymasının gösterilmesiyle verilerin normal yayılım belirtilerini gösteremedi. Bununla birlikte, çalışma süresi boyunca bireysel vaka ve ölüm sayılarının genel dağılımı, sıfırın alt değeriyle sınırlı, kesikli bir dağılım göstermiştir. Büyük dalganın kümülatif vakalar ve ölümler olarak matematiksel açıklaması, Richards modelini iyi bir regresyonla izledi (r>0,996). Yerleşik analiz, salgınların incelenmesi için tıp alanında değerli olabilecek basit, ucuz istatistiksel programlar kullanılarak ölüm/hastalığa dayalı pandemi etkisinin hızlı nicel değerlendirmesi için bir kilometre taşı görevi görmektedir.

Anahtar kelimeler: Kontrol grafikleri, COVID-19, morbidite/mortalite, Yeni Zelanda, Pareto grafiği, Richard Modeli

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Introduction

Coronavirus disease 2019 (COVID-19) pandemic is a newly emerging viral contagious ailment that has disseminated around the globe since the end of the year 2019. It is also known as novel CoV strain (2019-nCoV) and Severe Acute Respiratory Syndrome CoV-2 (SARS-CoV-2) which was expected to have emerged from Wuhan (1). Despite its low mortality rates - compared with the other previously known major outbreaks through the reported human history- yet it has changed the modern civilization era forever from different perspectives (2). Due to its risk and hazard associated with human health, numerous databases have been evolved through many organizations around the globe to monitor and record the progression of the pandemic disease. Every day, increasing morbidity and mortality data amount brings about the accumulation of a large amount of data (3). Through traditional statistical approaches, the analysis and the interpretation of the established records where data size and complexity are challenging and takes a lot of time (4). Thus, crucial conclusions might be obscured and become hidden within a huge number of figures. However, appropriate processing of the dataset would deliver useful qualitative and quantitative information for better understanding and investigation of the outbreak that can aid in decision-making and management of the catastrophic situations.

Conventional statistical analysis tools are of great importance in dataset interpretation and examination (5). Several statistical software platforms have been developed that could provide fast, effective and time-saving with minimum errors (6). However, it is not sufficient to rely only on the classical investigation using statistical methods when considering highly complex and large size databases of the epidemics which may obscure fundamental and useful information. Heuristic investigation steps are used frequently for the interpretation of large data in various scientific fields (7). However, due to the dynamic nature of the rapid infection dissemination, heuristic algorithms need continuous, swift and effective updates to the already existing dataset is mandatory to track the epidemic progress. This means in Layman's term that effective establishment of the right combination of processes is crucial for breaking complicated records into simple useful and understandable information (8). Establishing effective quantitative risk and health hazard metrics are critical for the understanding of the outbreak trend and dynamicity. These metrics could be delivered through the application of complementary statistical means and techniques.

Statistical Process Control (SPC) methodologies constitute a set of unique techniques that were principally used for industrial processes but have been adopted for other non-industrial fields (9). In these studies, different SPC means were conducted in a timely manner to derive a useful conclusion about the inspection characteristics being studied through trending patterns and behavior. In this following investigation study, complimenting analysis steps will be performed leading to an outbreak modeling through two parameters viz. morbidity and mortality with the possible future implementation of a novel approach of a quantitative index for the public health severity impact based on these two parameters. The current case investigation aimed to provide a useful perspective for SPC application extension in the understanding of microbial outbreaks in different territories. The subject study of this investigation is a selected country case from Oceania's geographical region.

The present study divided into four sections is made up of this scheme: In the first section, the collection of a dataset from an official internet monitoring official site for COVID-19 worldwide spreading which will be subject to data segregation, stratification and arrangement for further processing. In the second section, preliminary diagrammatic visualization of chronological data relation pattern from the reported record is conducted through statistical programs. In the next section, the application of SPC tools is conducted to examine the pattern, tracking outbreak behavior and extracting the main wave for further modeling study. In the last section, modeling of the cumulative number of cases and deaths is conducted through computer programs.

Material-Method

The current investigation focuses on multidimensional statistical analysis on the processed database of COVID-19 outbreak in a selected country (viz New Zealand) to determine quantitative metrics for disease severity impact on the public health based on morbidities and mortalities. The starting point for the present analysis is a database that is available in either Comma Separated Values (CSV) or Excel file format. The generated dataset would be further processed using several program engines. Each software contains a handy user helping guide for the understanding of each tab and the basic mathematical principle and equation behind the applied method, in addition to the online help guide. Program Platform consists of Minitab V 17.1.0, GraphPad Prism V 6.01 and CurveExpert V 1.40 software. Essentially, Minitab is applied for SPC tools including Pareto charts and control charts, in addition to data visualization graphs such as Contour plot and 3D-figure. On the other hand, GraphPad Prism is used for conventional statistical analysis involving the descriptive statistical analysis and CurveExpert is considered for the model fitting of the dataset.

Database Source

Web site European Union (EU) Open Data Portal https://data.europa.eu/euodp/ en/data/ dataset/covid-19-coronavirus-data/ resource /55e8f9 66-d5c8-438e-85bc-c7a5 a26f4863 provides up-to-date “COVID-19-geographic- distribution-worldwide” Excel or CSV database as could be seen in Figure 1 (10). This dataset was filtered and stratified based on the country from which the New Zealand record was isolated and arranged chronologically. Data were further subjected to processing by calculating the cumulative number of cases and deaths recorded pertaining to COVID-19. The overall time period covered was from 31 December 2019 to 25 September 2020. The major wave will be extracted and subjected for further analysis and investigation through descriptive statistics and chronological modeling.

Subject Study

New Zealand is the selected case study pertaining to a vicinity called Australasia, along with Australia (11). It also forms the southwestern extremity of the geographic and ethnographic region called Polynesia (12). The term Oceania is usually accustomed to denoting the broader region encompassing the Australian continent, New Zealand and various islands within the ocean that aren't included within the seven-continent mode. It is one of the best examples to be investigated for COVID-19 pandemic analysis because it is a remote country that does not share borders with any other countries and isolated by a large mass of water which provides an excellent opportunity to study the pattern of the infectious disease spreading and impact on citizens with minimal effect from interfering factors such as traveling from other nations (13).

Preliminary Visualization: 3D-Scatter Plot

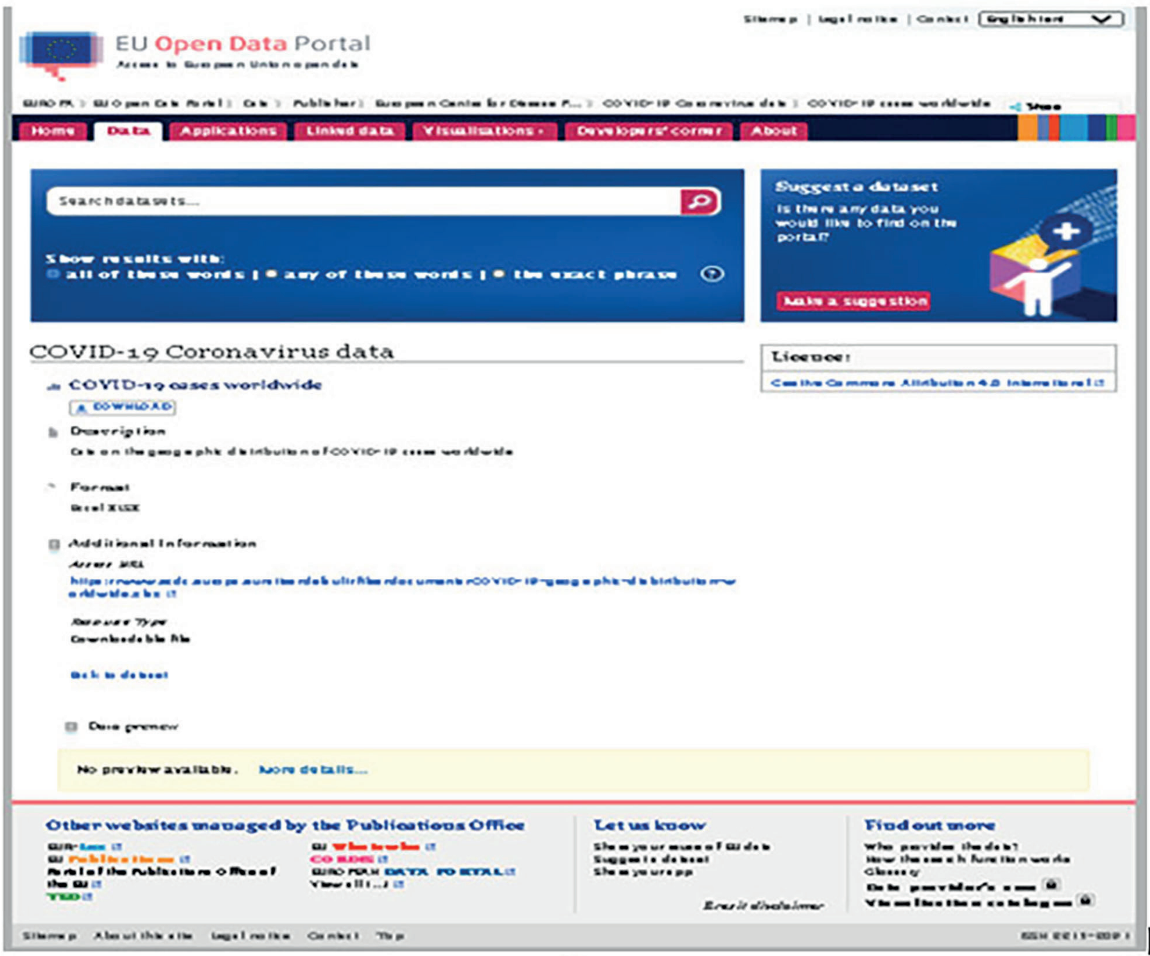
This is a Minitab-based analysis. A 3D scatterplot graph shows the actual data values of three changing variables against each other on the x-, y- and z-axes. Usually, predictor variables could be plotted on the x-axis and y-axis and the response variable on the z-axis (14). Creation of the 3D scatterplots in Minitab could be accomplished by choosing (Graph → 3D Scatterplot). The 3D scatterplot could be rotated simply to view it from different angles by click on the created plot to activate it, then selecting of **(Tools → Toolbars → 3D Graph Tools).** Figure 1 shows graphical steps for graph creation.

Preliminary Visualization: Contour Plot

This is a Minitab-based analysis. Contour plot displays a 3-dimensional relationship in two-dimensional area, with x- and y-factors (predictors) plotted on the x- and y-scales and response values represented by contours. From this perspective, a contour plot might be viewed like a topographical map, in which x-, y-, and z-values are plotted instead of longitude, atitude, and elevation. To create a contour plot in Minitab, choose **(Graph → Contour Plot)**. The number and colors of Icontour levels can be changed by right-clicking in the graph area and choosing **"Edit Area" if necessary, after creation** (15). This is illustrated graphically in Figure 1.

Initial Analysis Step: Pareto Chart

This is a Minitab-based analysis (16). It is a defining tool that spots the major contributors in the examined phenomenon as a count of the affected subjects by COVID-19 per month. Creation of Pareto diagram could be achieved through the following steps: Clicking on (Stat Tab → Quality Tools → Pareto Chart). A new window with the title "Pareto Chart" pops up. Then, "Category" should be selected into the "Defects or attribute data in" box followed by selecting "Count" into the box "Frequency in.". Finally, when the tab "OK." is pressed, a new window will open showing the Pareto chart. Steps could be seen in Figure 2.



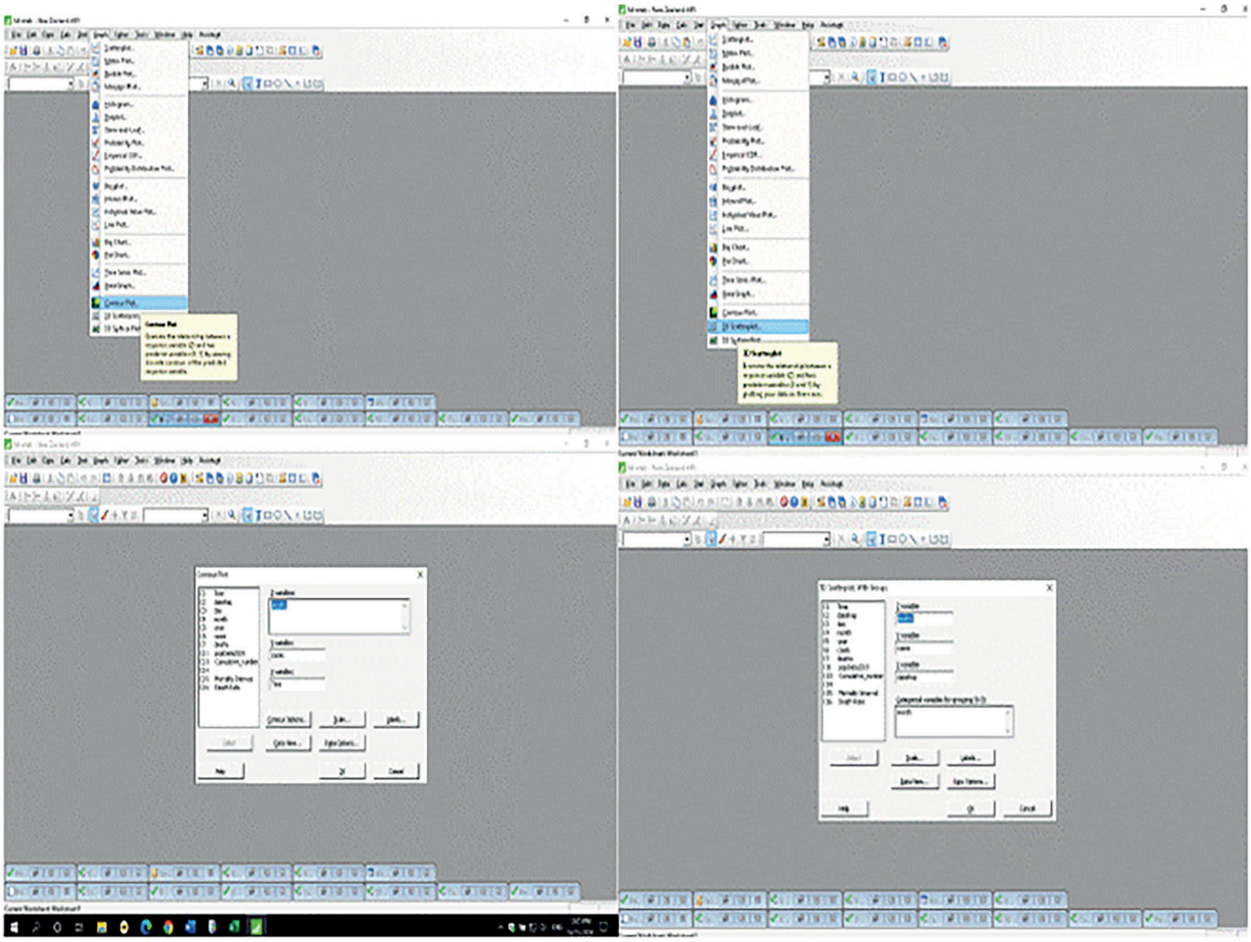


Figure 1: Source web page for downloadable database, 3D scatter plot creation steps using

Initial Analysis Step: Scatter Plot with Smooth Lines and Markers

Minitab software and contour plot generation steps in Minitab software.

This is an Excel-based graphical presentation. The raw dataset was processed using Microsoft Excel 2019. The following cascade of steps is followed selecting data range from the working sheet: insert → Insert scatter or bubble chart → Scatter Plot with Smooth Lines and Markers (17). Figure 2 below is demonstrating the steps. The chart would be used as a chronological illustrative tool for cumulative cases and deaths for the major wave attack.

Overall Trending of COVID-19 Morbidity and Mortality in New Zealand: Control Charts

To create a Laney U' chart, selection in Minitab should be as the following: (Stat → Control Charts →Attributes Charts → Laney U') (29). Then to create a G chart and plot the elapsed time between deaths, selection must be conducted as the following: (Stat → Control Charts → Rare Event Charts → G) (18). In the dialog box, either the "Dates of events" or the "Number of opportunities" between adverse events inputs could be entered. In the present case, the date when there is reported mortality incidents occurred, 'Dates of events' can be used, and the deaths column is specified. The illustration could be seen in Figure 3.

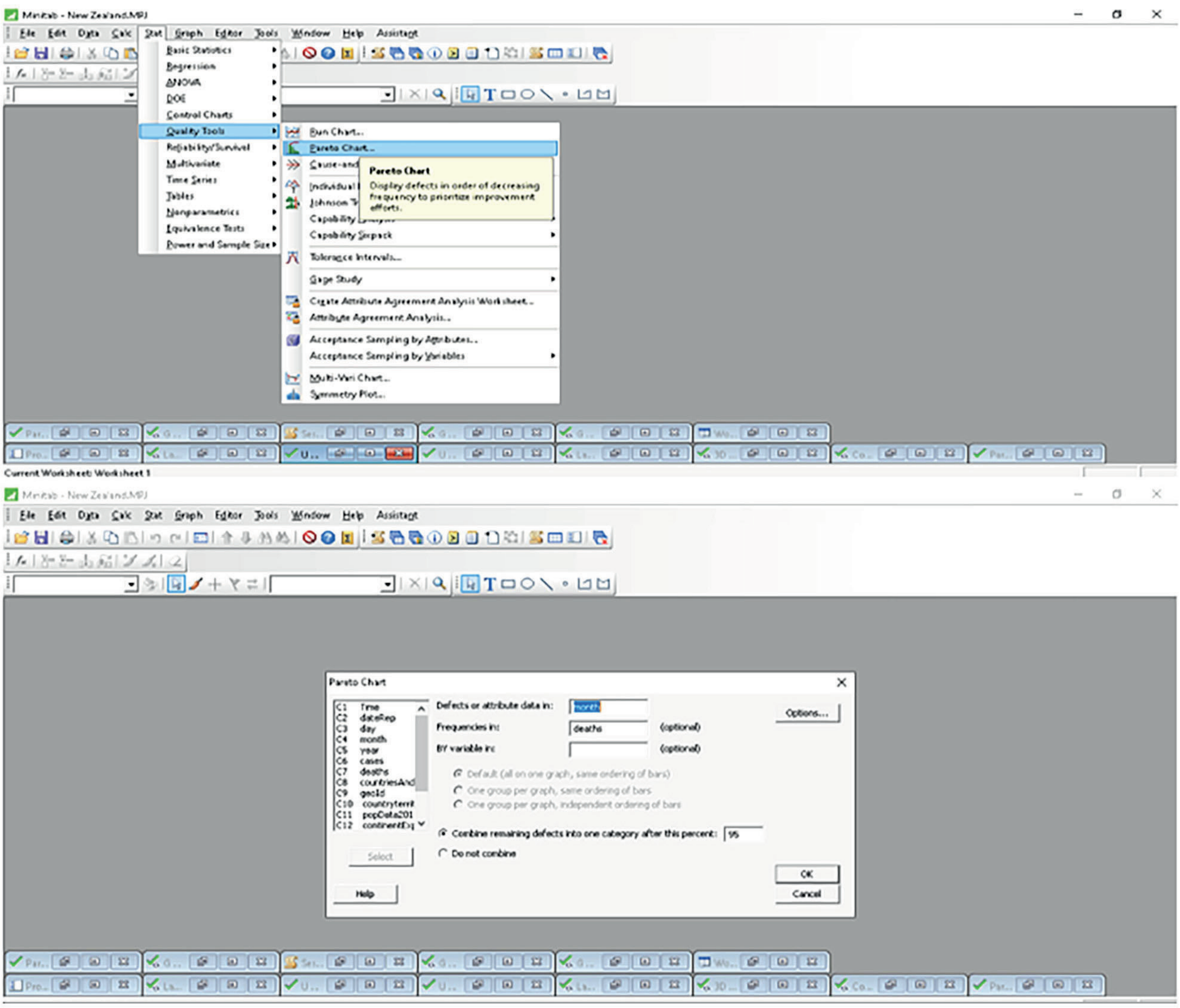
Major Wave In-Focus Analysis: Descriptive Statistics

GraphPad Prism is used for descriptive statistics record creation through entering data for column statistics. Column statistics are most often used with data entered on data tables formatted from Excel for column data (19). For experimentation, a column data table is created, and the sample data set is chosen: the column statistics could be selected for analysis from data entered onto XY or grouped data tables. Selecting column statistics analysis is selected through the following steps: By clicking analyze tab, column statistics could be selected from the list of analyses for column data. Choosing analysis options is conducted through checking boxes for the intended descriptive statistics tests. quartiles, median, Standard Deviation (SD), Standard Error of Mean (SEM), confidence interval, normality test, coefficient of variation, sum, skewness and kurtosis. This is demonstrated in Figure 4.

Major Peak of COVID-19: Best Curve Model Fitting

This software is an extensive detour fitting framework for Windows. XY information can be demonstrated utilizing a tool kit of straight regression models, nonlinear regression models, interpolation, or splines. More than thirty models are implicit; however, custom regression models may likewise be characterized by the client. The full-included diagramming ability permits an exhaustive assessment of the curve fit (20). The way toward finding as well as can be expected to be robotized by letting the program contrast database information with each model to pick the best fit as could be illustrated in Figure 4 as a model example for the steps. After opening the program columns of XY data are copied and pasted in the corresponding cells, selecting the button of “Curve Finder”, checking the boxes of the needed models or “All On” for screening of all models and press “Ok” tab.

During the analysis of the presented case of COVID-19 pandemic, several minor additional supportive conventional and classical statistical analysis would be used during the investigation argument to demonstrate the study parameters numerically.



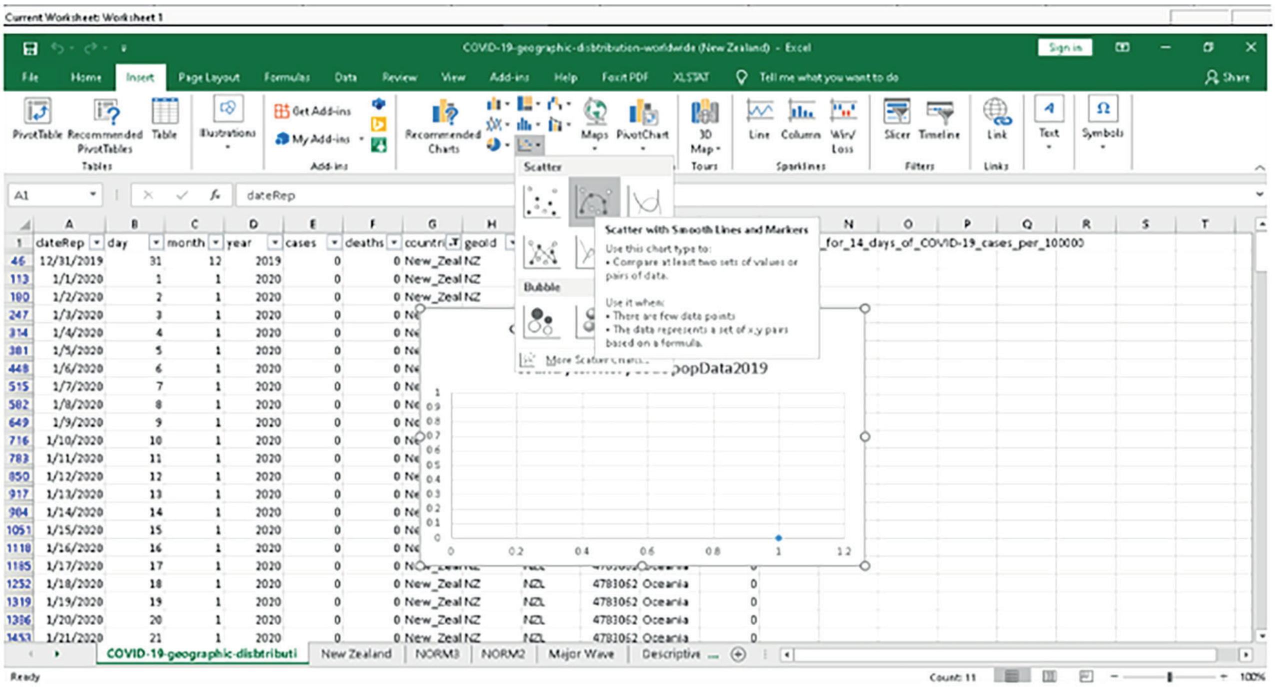
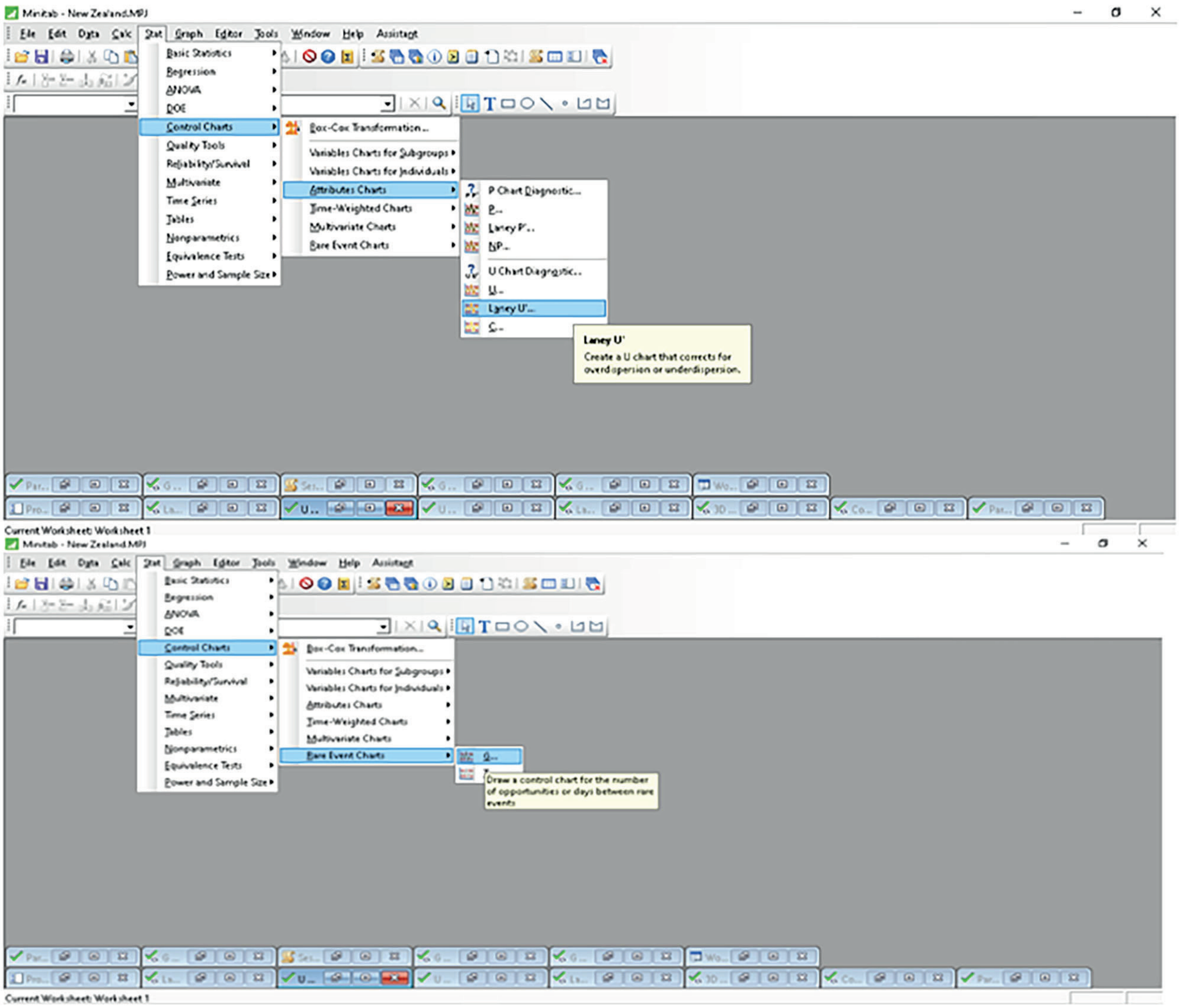


Figure 2: Pareto plot generation steps in Minitab software and time series graph generation in Microsoft Excel.



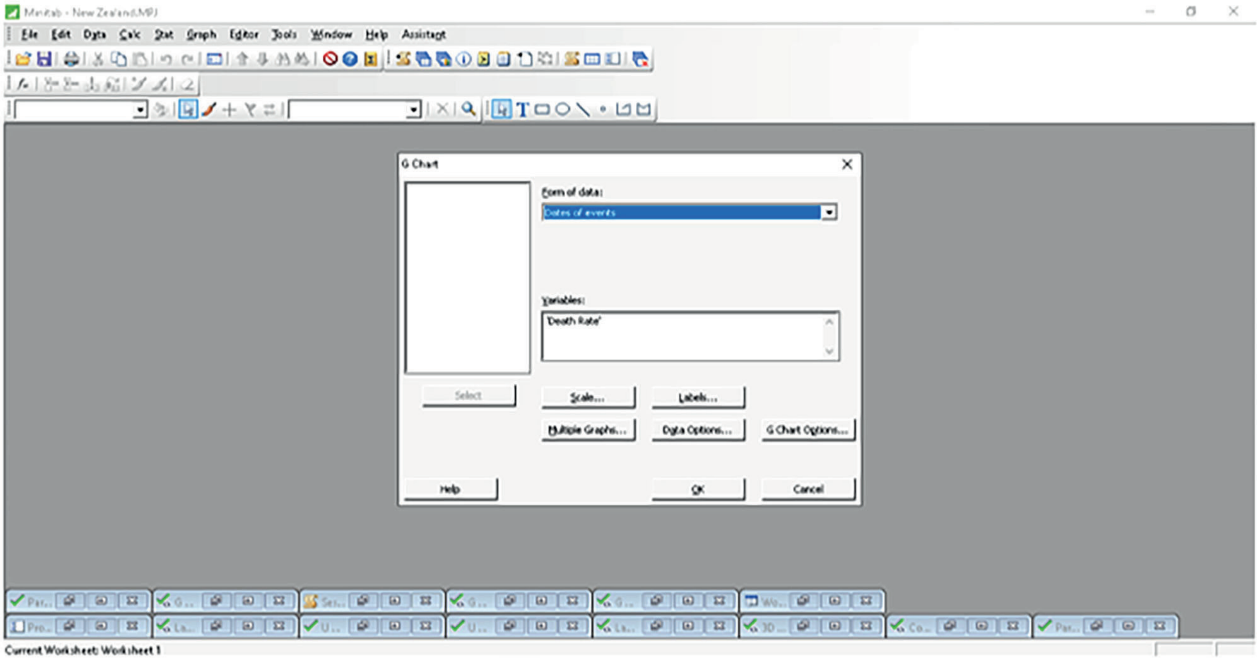
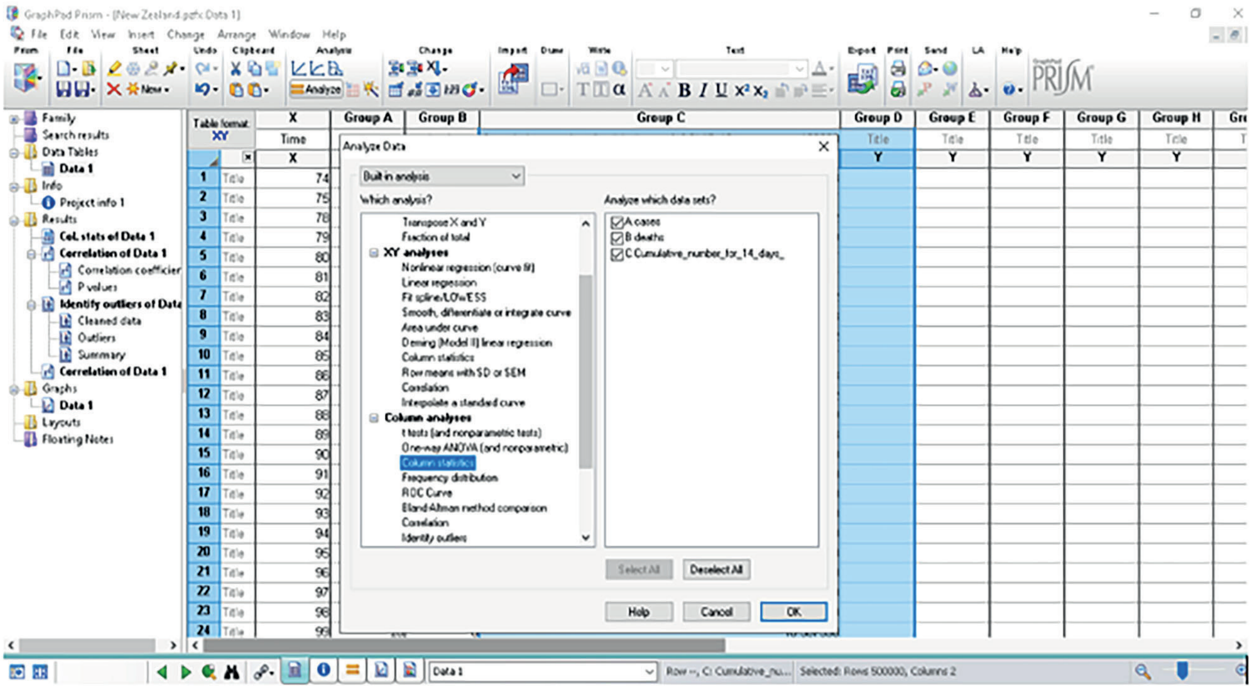


Figure 3: Control charts creation steps in Minitab software.



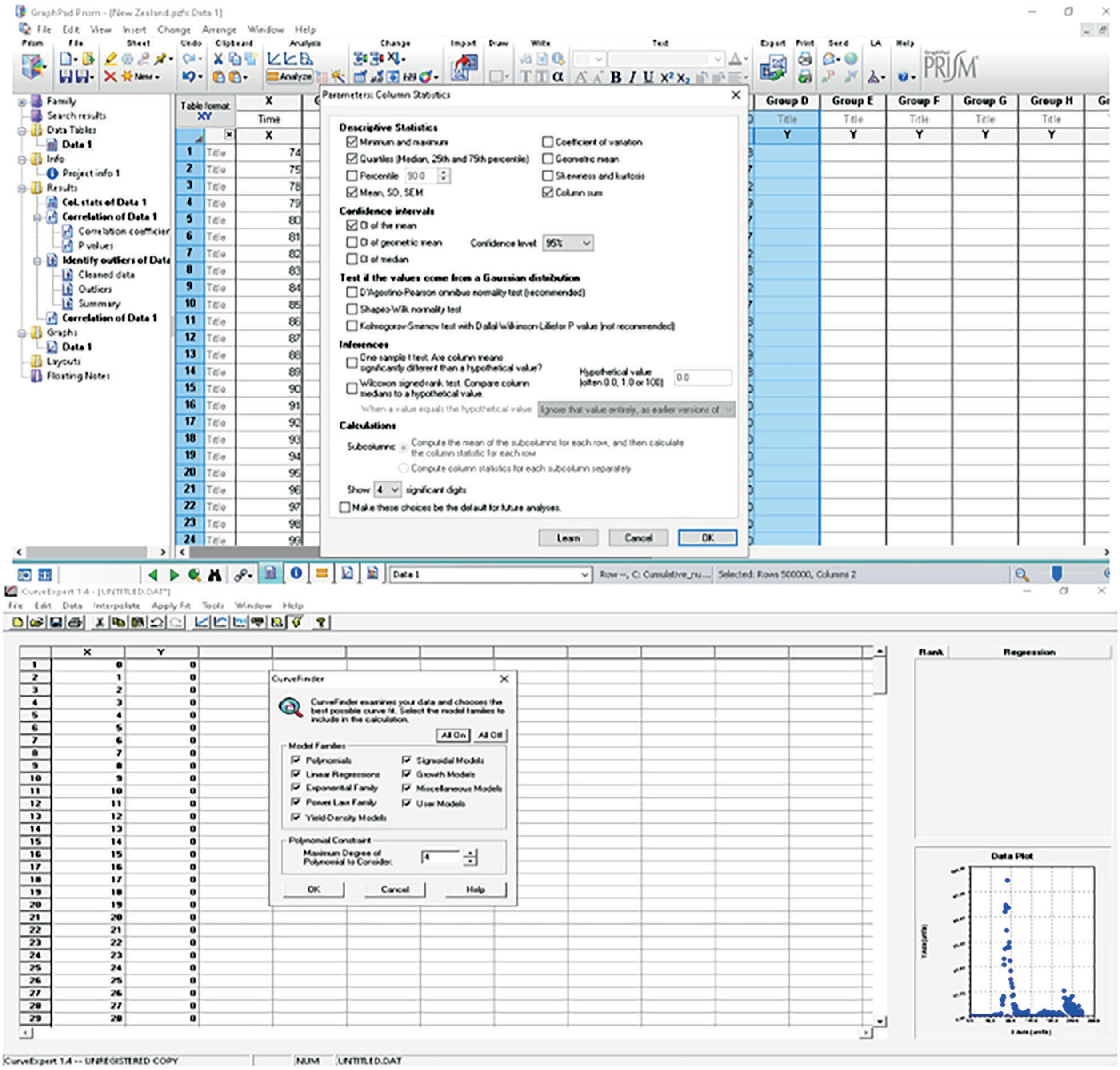


Figure 4: Descriptive statistics columns creation steps in GraphPad Prism program and curve fitting and modelling through CurveExpert program.

Results

New Zealand is a part of a wider region called Australasia when considering it with Australia. The total fraction of infected people contributed only by 0.03% and 0.02% approximately for nine months (from 31 December 2019 to 25 September 2020) and the major wave (14 March 2020 to 23 April 2020), respectively.

Preliminary Data Visualization

Low mortality incidence in relation to new cases could be deduced from the horizontal flattening 3D-scatter plot with only sparse days of single deaths or more and major cases could be observed in the first half of the examination period. On the other hand, the Contour plot showed two elevations in the number of cases as first main and second minor periods with none to a low level of mortality numbers in the major area except two relatively high spots following the major morbidity clusters.

These findings could be visualized complementarily in Figure 5.

Initial Investigation Step: Pareto Analysis and Scatter Plot with Smooth Lines and Markers

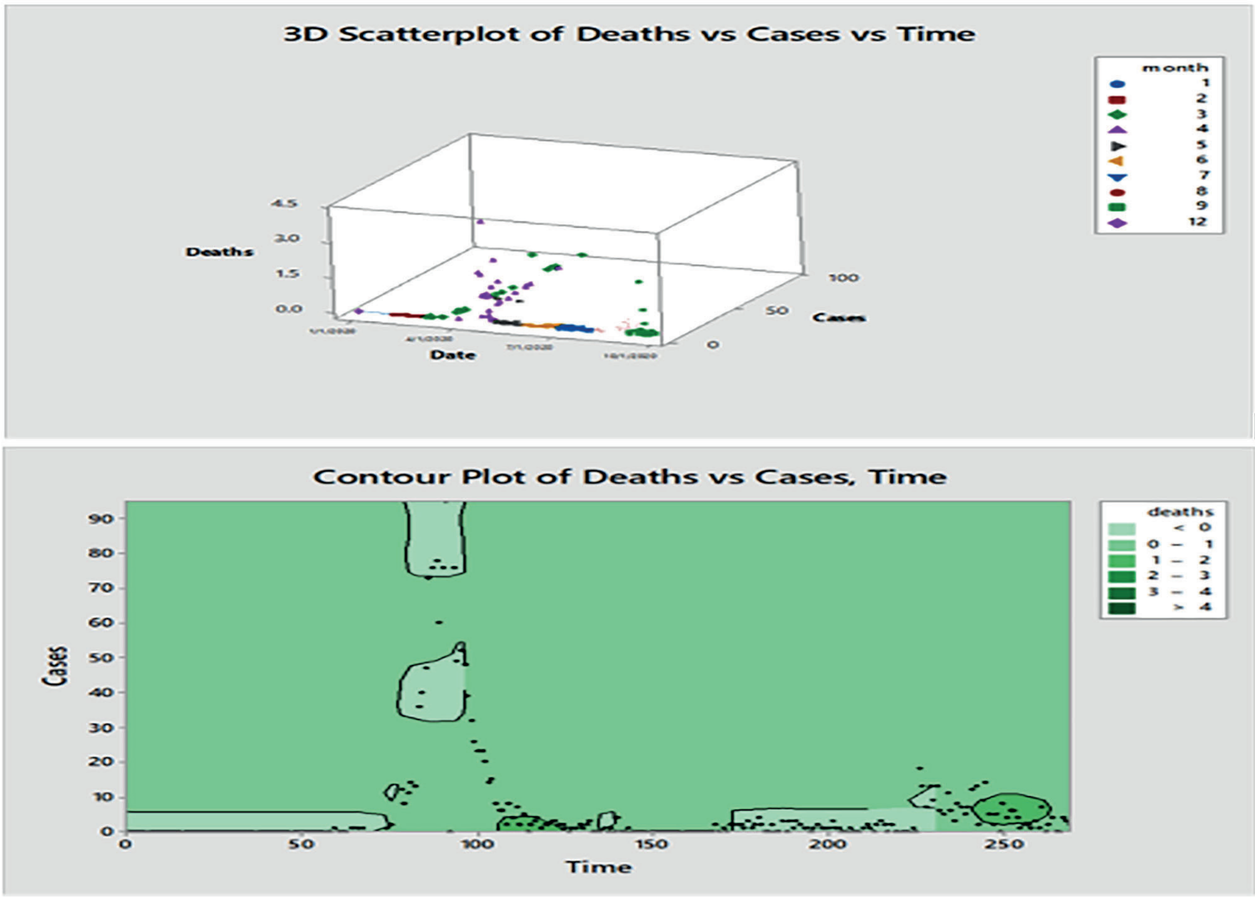
Focus analysis could be accomplished by determining the time of the major adverse health impact on the society using both morbidities and mortalities rates. Figure 5 shows the concept of the Pareto plot the determine the main influential period of the outbreak from the start of reporting till the end of the study on 25 September 2020. This finding was reinforced by the scatter plot chart that demonstrates cumulative cases and deaths of the main contributing period of the event chronologically showing the characteristic high (daily cumulative morbidity) and low (daily cumulative mortality) amplitude "S" shaped curve.

Process-Behavior Charts of COVID-19 Morbidities and Mortalities in New Zealand

Figure 6 is used for tracking the behavior of the mortalities and morbidities with time. Alarming points in the trending charts were meant for tracking the change. Control charts are characterized by higher and lower threshold windows marked as Upper Control Limit (UCL) and Lower Control Limit (LCL). Mean Line is indicated by Control Limit (CL) and specifically in U-chart as U (bar) line in-between both UCL and LCL.

Laney Attribute Charts and Elucidation of Data Pattern

The time elapsed between the first reported case and death was 30 days. While major mortalities wave tended to occur as a cluster of deaths during several consecutive days, morbidities tend to grow as a peak that is cleaved from the middle toward the decline phase of the main wave. Moreover, an evidence of a smaller wave of COVID-19 was evident at the end side of the attribute chart after a period of stability without deaths and none to low newly emerging cases that were observed by the regulatory agency.



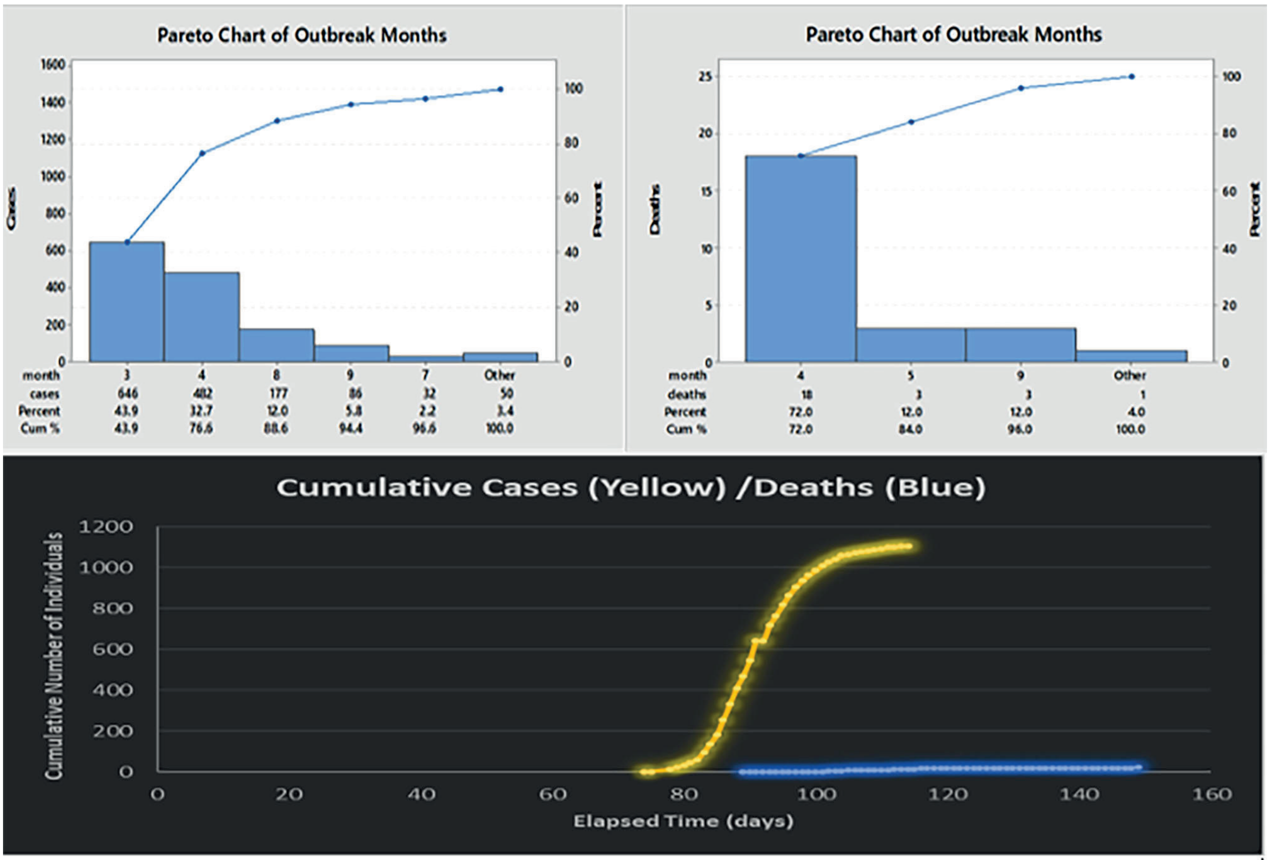


Figure 5: Preliminary data visualization using 3D (upper), Contour (green area) graphs, time periods of the major excursions in the number of reported cases and deaths in terms of months (non-cumulative daily individual enumeration) and days (major peak as cumulative).

Rare Event Control Chart and Mortality Rates Trending

A rare event control chart of G-type was used to describe mortality rate attributed to COVID-19 complications and interval numerically and visually as could be seen from Figure 6. The low mortality rate is indicated by the daily incident probability of 0.085. Interestingly, intervals between deaths tended to increase at the end of the study period indicated by the shift in the number of days (denoted by “2”). The final excursion (marked by “1”) is indicative of a “higher than usual” interval which is a desirable event between the first and the second waves at the silence period (45). The average period between two mortality days is about one week.

General Statistical Interpretation of COVID-19 Incidence in New Zealand

The total number of cases and deaths during the study period was 1107 and 16 individuals, respectively with a mortality rate of 1.45%. Table 1. The maximum number of daily deaths was 4 individuals. The Maximum reported number of daily impacted individuals by the outbreak was 95 with 75% of the total record falls within about half of this value. The mean ± standard error of the mean (SEM) for both cases and deaths was 28.4±4.4 and 0.4±0.1, respectively. Thus, a low frequency of excursion in both morbidities and mortalities could be observed during the monitored period of the epidemic in the country.

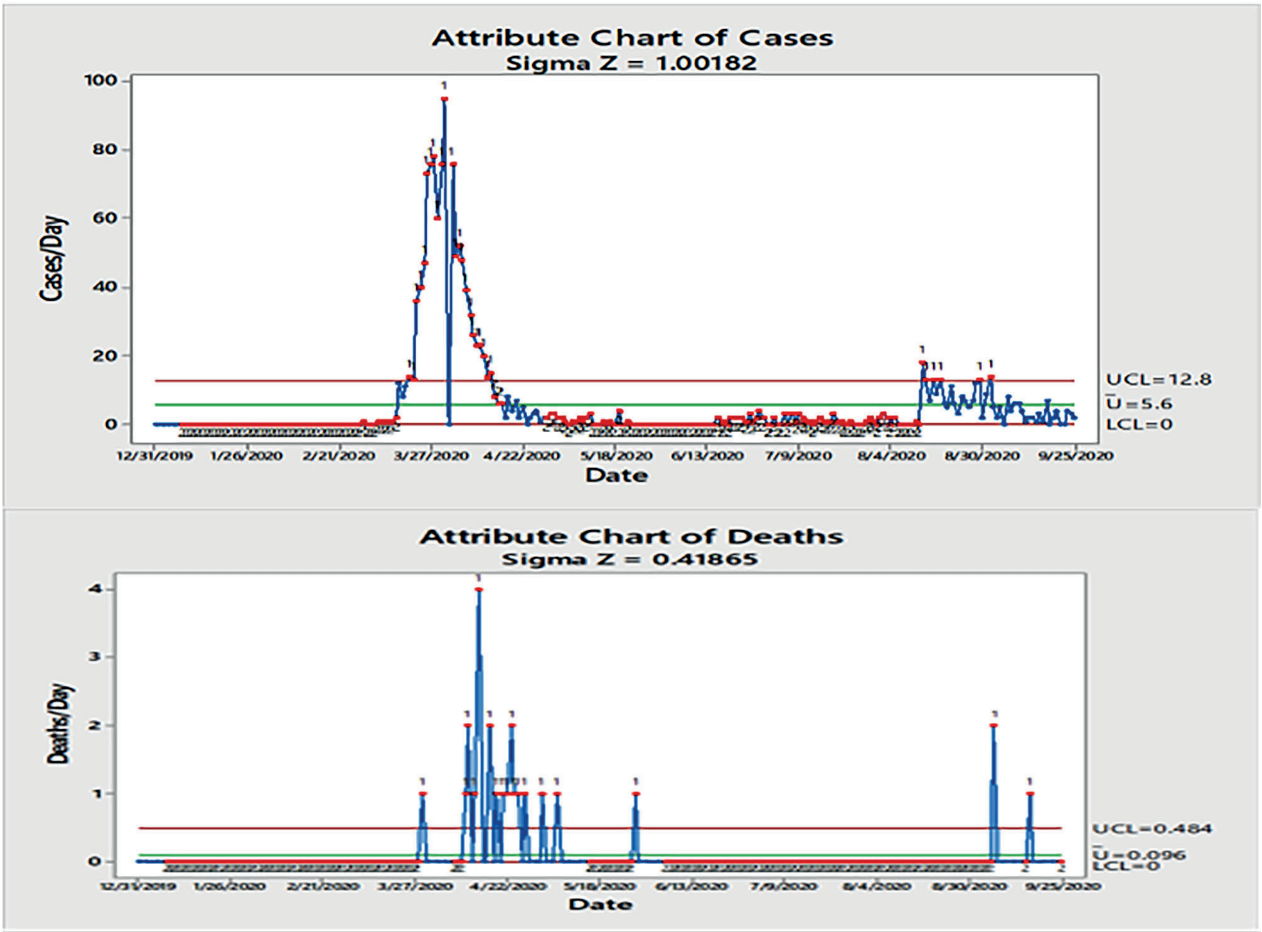
Modeling Approach of COVID-19 Epidemic Data in New Zealand

A Model fitting study showed that Richard modeling approach described well the sigmoid or “S” shaped curve of the cumulative dataset of the main peak or cluster of the morbidity or mortality rate, respectively. Equation (1) provides the description of the pattern with the constants a, b, c and d provided for both cases and deaths.

Richards Model: $y = \frac{a}{(1+e^{b-cx})^{\frac{1}{a}}}$ (1)

Where: y is the cumulative number of cases or deaths at elapsed time x and x is the elapsed time between 14 March 2020 (day 74) to 23 April 2020 (day 114) for cases and 29 March 2020 (day 89) to 28 May 2020 (day 149) for deaths. Coefficient data for morbidities and mortalities are as the following:
a(case) = 1.11651799027E+003,
b(case) = 1.40988665548E+001,
c(case) = 1.83346468159E-001,
d(case) = 1.18543299307E-001,
a(death) = 2.11906126736E+001,
b(death) = 1.74160714936E+001,
c(death) = 1.72030173153E-001 and
d(death) = 3.64561847880E-001.

The calculation for the equation through Excel function could be expressed as y=a/(1+exp(b-cx))^(1/d) with the values of constants and variables are translated into cells location in the worksheet. Theoretically, the mean daily increase rate of morbidity during the major wave period is theoretically calculated as 29.10 ≈ 29 cases per day with a range between 0.40 and 71.03. The average daily increase rate in mortality during the major wave period is theoretically calculated as 0.54 ≈ 1 death/day with a range of 0.02 to 1.14. This model could be visualized in Figure 6.



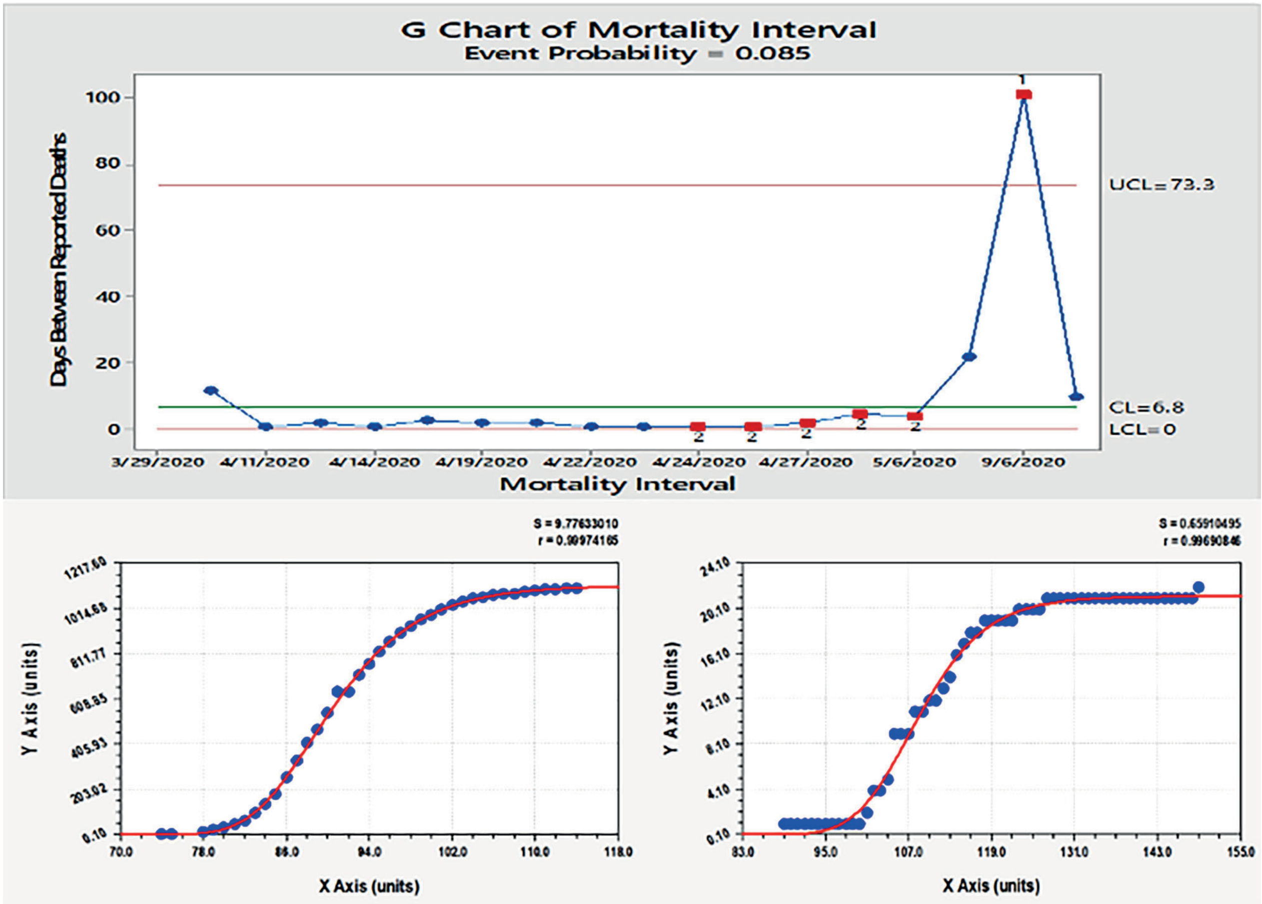


Figure 6: Laney attribute trending charts of cases and deaths chronologically, rare event (G) chart of the reported deaths arranged chronologically and modeling of the major wave of COVID-19 in New Zealand.

Table 1: Column statistics showing detailed analysis of the major wave of COVID-19 outbreak cases and deaths on daily basis.

Descriptive Statistics	Daily Reported Cases	Daily Reported Deaths
Minimum	0.0	0.0
25% Percentile	6.000	0.0
Median	15.00	0.0
75% Percentile	48.00	1.000
Maximum	95.00	4.000
10% Percentile	2.000	0.0
90% Percentile	76.00	2.000
Mean	28.38	0.4103
Std. Deviation	27.41	0.8497
Std. Error of Mean	4.390	0.1361
Lower 95% CI* of mean	19.50	0.1348
Upper 95% CI* of mean	37.27	0.6857
Lower 95% CI* of median	8.000	0.0
Upper 95% CI* of median	39.00	0.0
D'Agostino & Pearson omnibus normality test£		
K2	5.485	38.93
P value	0.0644	< 0.0001
Passed normality test (α = 0.05)?	Yes	No
P value summary	ns¥	****
Coefficient of variation	96.58%	207.12%
Skewness	0.9054	2.602
Kurtosis	-0.3885	7.790
Sum€	1107	16.00

** Confidence Interval ¥ Not Significant £ Recommended test in the program € Cumulative major wave*

Discussion

New Zealand is a remote country island located in the southwestern Pacific region with a country population census of about 4783062 citizens (10). The study focused – herein – in useful quantitative analysis of epidemics that would be useful in the understanding of the outbreak kinetics in terms of cases and deaths reported among the population. The study will be limited by the accuracy of the provided record of COVID-19 database.

Preliminary Analysis of Outbreak Data

Daily death rates were generally low in magnitude in comparison with the emerging number of the reported cases. An observation that has been reported previously by other researchers (21). Thus, mortality ratio is remarkably low in relation to other aggressive and fatal epidemics in the human history.

Initial Observation of Morbidity and Mortality Kinetics

There is a latency between the emergence of cases and reporting deaths as could be agreed with the observation in Figure 10 (22). While major excursions of the observed cases of COVID-19 occurred in March and April, most deaths followed in April and May with contributions over 75% and 80%, respectively (23). This finding was evident in the present study.

Process-Behavior Chart in COVID-19 Monitoring

Despite control charts were originally created for monitoring of the industrial processes during an early time in the 20th century, yet they found their usefulness in the study and analysis of the other fields of non-industrial inspection characteristics, including microbiological water quality, viable airborne particles, surgical site infection (SSI) and outbreaks (24). The current analysis showed a valuable use for tracking epidemic progress using trending charts for investigating the pattern, the width and magnitude. Interestingly, a sign of a smaller wave of COVID-19 was evident at the end side of the attribute chart after a period of calmness with no deaths and none or low newly reported cases that were observed by the authorities (25). In general, the emerged peaks of the cases demonstrated a sharp rise and slow decline in the daily observed rates. Laney modification of the process-behavior chart was selected as a conservative approach to correct for any distortion from the hypothetically assumed distribution required in count-type data (26). U-chart could be considered a generalization of the same concept of a C-type trending chart (27).

Descriptive Statistics

Death rate observed in the country showed low value below 1.5%. This is a positive outcome that has been reported by other investigators (28). While the total affected daily population showed a normal distribution pattern, the strongly skewed daily mortalities record showed non-Gaussian distribution with three-quarters of readings demonstrated by zeros and ones, indicating outbreak of limited mortality rate. Generally, a stable pattern could be concluded which is interrupted by primary and secondary wave peaks.

Modeling of COVID-19 in New Zealand

The adopted model herein showed a reasonable fit with the recorded dataset of COVID-19 in New Zealand. Richard's model has been implemented successfully in the previously reported microbiological outbreaks by researchers (29, 30). The model could serve as a quantitative description and public health hazard risk metric to measure deterioration or improvement of the counter epidemic measures within countries and to compare the level of the pandemic between different locations.

Conclusion

This paper focused on quantitative analysis of epidemics as a useful tool in the unbiased evaluation of COVID-19 outbreaks by healthcare practitioner. A unique approach is proposed for disease progression and tracking using a commercial statistical software platform. Quantitative analysis of infection cases and deaths was carried out using statistical process control methodologies. The major wave represents 75.15% of the total number of cases. Similarly, the overall estimated number of deaths and the major mortality attack accounted for 1.70% and 1.45%, respectively. The main excursions of the mortalities from the first wave contributed by 64.00% from the total epidemic record. While the Richard model should be investigated for other countries in the dataset, the principle of this mathematical expression might stand as a cornerstone for quantitative risk analysis of the outbreak based on both morbidities and mortalities during a certain time frame.

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N/A

Conflicts of Interest
No conflict of interest was declared by the authors.

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