Systematic Review and Meta-Analysis

Medicine

OPEN

Using the Kano model to associate the number of confirmed cases of COVID-19 in a population of 100,000 with case fatality rates

An observational study

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Abstract

Background: An important factor in understanding the spread of COVID-19 is the case fatality rate (CFR) for each county. However, many of research reported CFRs on total confirmed cases (TCCs) rather than per 100,000 people. The disparate definitions of CFR in COVID-19 result in inconsistent results. It remains uncertain whether the incident rate and CFR can be compared to identify countries affected by COVID-19 that are under (or out of) control. This study aims to develop a diagram for dispersing TCC and CFR on a population of 100,000 (namely, TCC100 and CFR100) using the Kano model, to examine selected countries/regions that have successfully implemented preventative measures to keep COVID-19 under control, and to design an app displaying TCC100 and CFR100 for all infected countries/regions.

Methods: Data regarding confirmed cases and deaths of COVID-19 in countries/regions were downloaded daily from the GitHub website. For each country/region, 3 values (TCC100, CFR100, and CFR) were calculated and displayed on the Kano diagram. The lower TCC100 and CFR values indicated that the COVID-19 situation was more under control. The app was developed to display both CFR100/CFR against TCC100 on Google Maps.

Results: Based on 286 countries/regions, the correlation coefficient (CC) between TCC100 and CFR100 was 0.51 (t = 9.76) in comparison to TCC100 and CFR with CC = 0.02 (t = 0.3). As a result of the traditional scatter plot using CFR and TCC100, Andorra was found to have the highest CFR100 (=6.62%), TCC100 (=935.74), and CFR (=5.1%), but lower CFR than New York (CFR = 7.4%) and the UK (CFR = 13.5%). There were 3 representative countries/regions that were compared: Taiwan [TCC100 (=1.65), CFR100 (=2.17), CFR (=1%)], South Korea [TCC100 (=20.34), CFR100 (=39.8), CFR (=2%), and Vietnam [TCC100 (=0.26), CFR100 (=0), CFR (=0%)].

Conclusion: A Kano diagram was drawn to compare TCC100 against CFT (or CFR100) to gain a better understanding of COVID-19. There is a strong association between a higher TCC100 value and a higher CFR100 value. A dashboard was developed to display both CFR100/CFR against TCC100 for countries/regions.

Abbreviations: CC = correlation coefficient, CFR = case fatality rate, CFR100 = case fatality rate per 100000 population, PMC = PubMed Central, TCC = total confirmed cases, TCC100 = total confirmed cases per 100000 population.

Keywords: case fatality rate, COVID-19, Google Maps, infection rate, Kano model, total confirmed case

1. Introduction

Whenever a new disease (such as COVID-19) spreads, one of the most frequently asked questions is: What is the case fatality rate (CFR), defined as the number of deaths divided by the number of confirmed cases.[1] CFR pertains to the following questions: How deadly is the disease? How many people will die as a result of this outbreak?[2–4] SARS, MERS, Ebola, and H1NI yielded real CFRs of 9.6%, 34.4%, 73%, and 0.4%, respectively.[5–9] Thus, the CFR for COVID-19 is of interest to a number of researchers.

This study was supported by a grant provided by An Nan Hospital, China Medical University, Tainan, Taiwan (ANHRF105-07) that enabled us to complete this study.

The authors have no funding and conflicts of interest to disclose.

All data were downloaded from the website database at Github. The datasets generated during and/or analyzed during the current study are publicly available.

Supplemental Digital Content is available for this article.

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How to cite this article: Hsu S-Y, Chien T-W, Yeh Y-T, Chou W. Using the Kano model to associate the number of confirmed cases of COVID-19 in a population of 100,000 with case fatality rates: An observational study. Medicine 2022;101:37(e30648).

Received: 24 May 2020 / Received in final form: 18 August 2022 / Accepted: 19 August 2022

http://dx.doi.org/10.1097/MD.0000000000030648

Key Points

- TCC100 and CFR100 are used to supplement the traditional CFR in epidemiology, which does not take population density into consideration.
- Verifying the one-dimensional quality of the Kano diagram to compare countries and regions in COVID-19 situations.
- To complement the traditional dashboards, which do not take into account population density, an app was developed for the display of CFR100 and CFR100/CFR online.

1.1. Comparing CFRs and incidence rates in a specific population

The search term "case fatality rate" can be found in PubMed Central (PMC).[5] The incidence rate of an invading disease has been suggested in the literature.[6–10] On August 16, 2022, no study has been found that incorporates both CFR100 and total confirmed cases (TCC) in a population of 100,000 (here referred to as CFR100 and TCC100, respectively). Italy, for example, had a CFR of 13% for COVID-19 as of April 12, 2020. Based on the resident densities of each population, numerous countries/regions outperformed Italy in both CFR100 and TCC100.

In addition, reports on Taiwan's[11–13] and Vietnam's[14–23] prevention measures can help verify the accuracy of CFR (or CFR100) and TCC100 that should be mentioned in COVID-19 reports containing "certain tolls."

1.2. The Kano model used for comparisons

Based on a theory developed in 1984 by Professor Noriaki Kano,[24] the Kano Model categorizes products into 3 main quality categories: must-be, one-dimensional, and attractive.

Various articles were found using the keywords "Kano Model" [Title/Abstract] in PMC, with the following results: Hospital burn service providers were required to measure patient satisfaction with their care and categorize the services.[25] A cross-sectional study was conducted at Missouri University of Science and Technology's Student Health Services using the Kano survey.[26] Based on the Kano Model, healthy fast-food chains sought to differentiate themselves from other fast-food chains and understand how customers perceive service attributes.[27]

A number of relevant studies applied the Kano Model to importance-performance analysis by displaying results in 4 quadrants in the literature.[28–30] One of the challenges we encountered was that drawing the plot was tedious, and categorizing the items or products was cumbersome with the Kano approach.

1.3. How to draw the Kano model on Google Maps

Several authors[31] presented codes in 2018 for classifying entities according to the Kano framework and plotting the results for rapid inspection and visualization. Despite this, the code was written in R, a computer language that is unfamiliar to the general public. The results were also displayed on a static plot rather than an animated dashboard that would allow users to easily identify the product (or item) of interest. This type of data is currently extremely difficult to process and analyze, and it is prone to human error when data are classified and drawn using the Kano Model or importance-performance analysis.

The lack of dedicated software solutions may substantially limit the application of the Kano Model in healthcare settings. To narrow the gap, we are motivated to present an easier method of displaying COVID-19 situations on CFR/CFR100 against TCC100.

1.4. Objectives

In this study, we developed codes to visualize the Kano diagram to categorize CFR/CFR100 against TCC100 based on countries/regions and illustrate COVID-19 situations under control and non-control.

2. Methods

2.1. Data sources

COVID-19 outbreak data were obtained from Github,[32] a website that contains information about confirmed cases and deaths in infected countries/regions as of April 12, 2020. All downloaded data (see Supplemental Digital Content 1, http://links.lww.com/MD/H341) are publicly available on the website.[32] As all of the data were obtained from Google Sheets, ethical approval was not required for this study.

2.2. Quantitative Kano modeling

Although the Kano Model[24] was originally designed as a qualitative method, quantitative extensions have been proposed to enhance its actionability and applicability[33,34]; see Figure 1. In a quantitative Kano diagram, entities are represented in the top, middle, and bottom panels.[35] A plot should be created by recoding the results from 2 domains (for instance, CFR on Axis Y and TCC100 on Axis X) as coordinates. As part of the current study, Google Maps was integrated to demonstrate the Kano approach for displaying COVID-19 situations across the globe.

2.3. Computations step by step

1. Boundary curves are critical to the Kano diagram

Two types of computer codes of boundary curves were developed in this section. Drawing boundary curves to categorize entities on the Kano diagram is essential and necessary.

2. The way to plot boundary curves

The basic function of a curve (named hyperbola as upper and lower limited curves) was derived as y = (x × x − 3 × x)/

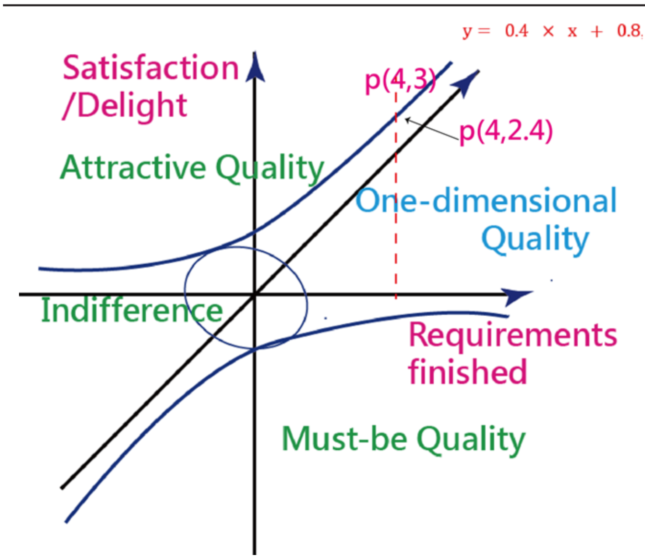

Figure 1. The Kano diagram (Note: 2 boundary curves are used to divide members into 3 panels in colors).

(2 × x − 2), where y denotes the latitude on Google Maps, and × represents the longitude. The rotation for a specific point at p(x,y) can be made from the equations y' = y × cosθ + x × sinθ and x' = x × cosθ−y × sinθ, where we are only concerned with the new position of y' instead of x', due to × being anchored and fixed to reflect the new position at p'(x, y').

3. The way to classify entities into Kano classes

Using computer codes, we classified entities or members into classes based on their coordinates on a map. In this method, the formulas for forming a line (Li: y = ax + b) with 2 points of p(x1, y1) and p(x2, y2) was applied in Equations 1 and 2.

$$y1 = a \times x1 + b,$$

$$y2 = a \times x2 + b,$$

From Equations 1 and 2, Equation 3 can be obtained by the arrangement after Equation 1 minus Equation 2. Also, parameter b in Equation 4 can be obtained via Equation 2.

$$a = \frac{(y1 - y2)}{(x1 - x2)}$$

$$b = y2 - (a \times x2),$$

$$a = \frac{(2 - 2.8)}{(3 - 5)} = 0.4$$

$$b = 2.8 - (0.4 \times 5) = 0.8,$$

$$y = 0.4 \times x + 0.8$$

For example, it is assumed that 1 entity is located at p(4, 3) = p(x, y), and 2 points beyond x = 4 (i.e., greater or smaller than 4) on the upper limit curve are known (e.g., p(3, 2) and p(5, 2.8)) because the coordinates of the upper curve on the Kano diagram have been known previously. A line (L4: y = ax + b) can be formed by Equations 3–5. The entity located at p(4, 3) can be compared with the L4 by judging the y value(=$0.4 \times 4 + 0.8 = 2.4$) via Equation 5 and classified into the attractive zone because the y value of p(4, 3) is greater than the y value of 2.4 on the upper limit line.

Similarly, we can apply this principle to determine whether the entity belongs to either the unidimensional or must-be quality category when the vertical coordinate is beyond or below the limit line on the Kano diagram; see the visual coordinates of the point p(4, 3) and Equation 5 in Figure 1. As such, the count in each classification can be obtained.

2.4. Coordinates of CFR100 against TCC100 on the Kano diagram

On the Kano diagram, 2 axes (i.e., CFR/CFR100 on Y and TCC100 on X) were plotted as coordinates. The bubbles were colored according to the features (e.g., must-be, one-dimensional, attractive) and sized according to the ratio of deaths divided by a 100,000-person population.

2.5. A dashboard on Google Maps to present the CFR100 and TCC100

To display the daily results across various regions, a dashboard was developed. We developed an app that displays both CFR/CFR100 against TCC100 on Google Maps.

The following approaches are available for the use of TCC100 data on the Kano diagram:

Step 1: The data of CFR100, TCC100, and bubble size are arranged in 3 columns in a spreadsheet.

Step 2: The 3 columns of data are copied and pasted onto the website[36] based on the tutorial material.[37]

2.6. Statistics and tools

The correlation coefficient (CC) (r) was used to determine the association power between CFR/CFR100 and TCC100. The CC t value was calculated using the following formula (=CC$\times\sqrt{\frac{n-2}{1-CC\times CC}}$).[38] The CC and counts in each part of the Kano diagram were computed. The significance level was set at Type I error (=0.05).

A total of 4 visualizations were used to present the study results: choropleth maps,[39] bar charts, Kano diagrams,[24] and pyramid plots.[40] Dashboards were used to display them on Google Maps. The study flowchart is presented in Figure 2.

3. Results

3.1. Using the Kano model to display 3 features on Google Maps

Based on 286 count data (i.e., 11, 94, 1810.92 [t = 37.87]), we calculated the CC between TCC100 and CFR100 to be 0.51 (t = 9.76). The pair of TCC100 and CFR, on the other hand, has CC = 0.02 (t = 0.3) and counts (67, 138, and 81 on the Kano diagram), as shown in Figure 3.

It has been shown that Andorra has the highest CFR100 (=6.62% = 37 deaths/723 infections/0.77 per 100,000 population), with TCC100 (=935.74 infections per 100,000 population), and CFR (=5.1%) compared to New York (CFR = 7.4%=19413/263292) and the UK (CFR = 13.5%=18151/134638) based on a scatter plot of CFR and TCC100.

This study examined 3 representative countries/regions: Taiwan[TCC100(=1.65), CFR100 (=2.17), CFR(=1%)], South Korea[TCC100(=20.34), CFR100 (=39.8), CFR(=2%)], and Vietnam[TCC100(=0.26), CFR100 (=0), CFR(=0%)] up until April 12, 2020 compared with (1) Taiwan[TCC100(=1.65), CFR100 (=2.17), CFR(=0%) CFR(=1%)], South Korea[TCC100(=20.34), CFR100 (=39.8), CFR(=2%)], and Vietnam[TCC100(=0.26), CFR100 (=0), CFR(=0%)] up until April 12, 2020.

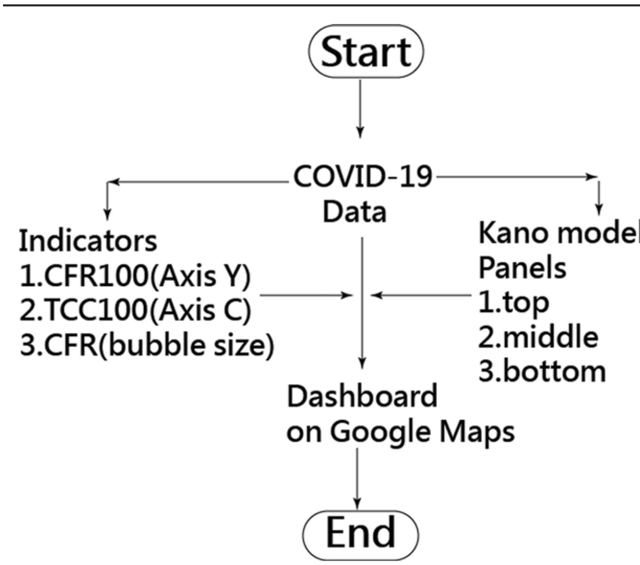

Figure 2. Study flowchart (Note: 3 elements are used to draw the Kano diagram).

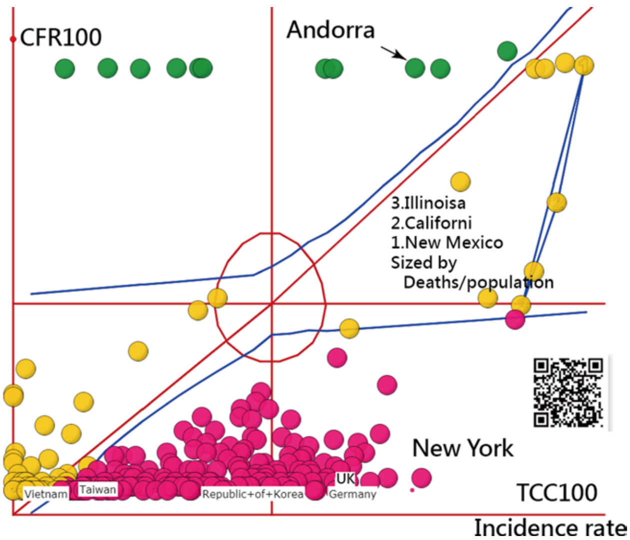

Figure 3. TCC100 and CFR100 on the Kano diagram (Note: a higher correlation coefficient exists with corr. = 0.51, t = 9.76).

3.2. Taiwan example of COVID-19 under control

There is evidence that Taiwan's COVID-19 situation is under control

This can be seen in the bottom left-hand corner of Figures 3 and 4. As of May 14, 2020, most of the confirmed cases were imported from abroad. Figures 5 and 6 illustrate the percentage of citizens (86%) in the 20 to 29 age group. The top 3 cities/counties were Taipei, New Taipei City, and Taoyuan (Fig. 7). To obtain more information, readers are encouraged to scan the QR code in Figure 7 or click on the link.[41]

Of the 393 confirmed cases, 338 (86%) were imported from overseas, 52% were females, 71% were asymptomatic and mild, 21% were moderate, and 7.5% were severe, including 6 deaths. As of April 12, 2020, 12 patients were still in intensive care units. In total, 114 individuals were discharged from hospitalization and released from quarantine.[42]

3.3. Online dashboards shown on Google Maps

All the QR codes in figures are linked to the dashboards.[41,43,44] Readers are suggested to examine the displayed dashboards on Google Maps.

4. Discussions

4.1. Principle findings

In this study, we found that the CC between TCC100 and CFR100 was 0.51 (t = 9.76), a significant difference from the combination of CC = 0.02 (t = 0.3) for TCC100 and CFR. Andorra was overlooked as having the highest CFR100 with TCC100 (=935.74 infections per 100,000 population), (=6.62% =37/723) comparing the CFR (=5.1%) to New York (CFR = 7.4%) and the UK (CFR = 13.5%). CFR and TCC100 are plotted on the traditional scatter plot.

4.2. What this finding adds to what we already knew

CFRs have been used in numerous publications to compare death rates for specific diseases.[5] A population of 100,000 can be used to calculate the incidence rates when compared to CFR. It is reasonable to compare them with 1 another.[6–10]

The purpose of this study was to combine CFR (or CFT100) and TCC100 on a dashboard using the Kano diagram to display, which is a novel, innovative approach that is rarely seen in the past literature. As a result of such a design, the current COVID-19 pandemic is viewed from a new perspective. As an example, Italy had a high CFR of 13% for COVID-19 up until April 12, 2020, but this was less than the country of Andorra, the state of Washington, USA, and other countries/regions based on CFR100. In comparison with COVID-19 showing the CFR in previous studies,[2,45] we should take the population density into consideration.

Furthermore, countries/regions that performed well in combating COVID-19 should be highlighted (see, e.g., Figs. 3 and 4 left-hand bottom corner), such as Vietnam, Taiwan, Hawaii (US), and Fujian (China). The coordinate for entities will be automatically and immediately adjusted to an appropriate point on the dashboard once the data are updated.

4.3. What it implies and what should be changed

We illustrate Taiwan, 1 example of a successful response to the COVID-19 crisis shown in Figures 5 to 7. In an article published by NBC News,[46] it was reported that the Taiwanese government and the people have learned from the experience of the 2003 SARS outbreak.

As a result of the current crisis, we were well prepared. Taiwan has the lowest incidence rate, approximately 5 cases per 100,000 people, among nearly 200 countries and regions affected.[19,46,47] It is worth noting that the Taiwanese government mandates that hospitals test for and report cases of COVID-19. The policy helped the government identify those infected, trace their social contact history, and isolate those who were in contact. In terms of preventing community spread, Taiwan's government was ahead of the world, successfully containing. As early as January 21, 2020, Taiwan had its first confirmed case of the disease.[16–18,48]

Taiwan's Centers for Disease Control (CDC) established a Central Epidemic Command Center on January 20, 2020, which quickly implemented a series of epidemic control measures. In addition to investigating confirmed and suspected cases, the command center also coordinates the crisis response across Taiwan by allocating funds, mobilizing personnel, and advising on disinfection policies in schools. Taiwan was the first country to ban direct flights from Wuhan and a few other Chinese cities on January 26, 2020. Taiwan imposed border control 5 days after confirming its first case, preventing

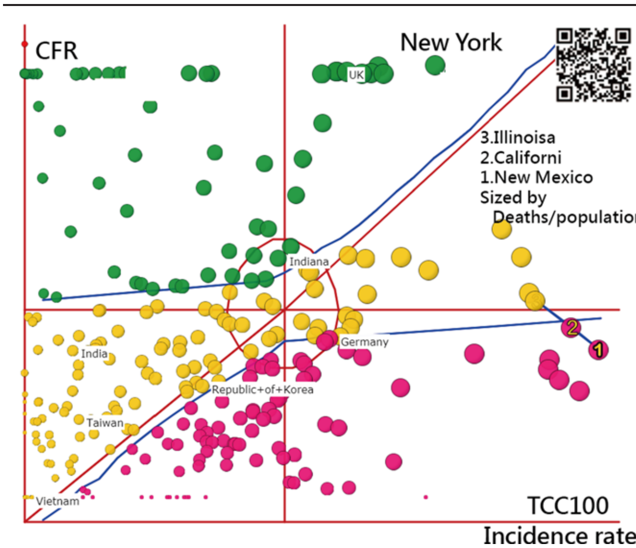

Figure 4. TCC100 and CFR on the Kano diagram (Note: a lower correlation coefficient exists with corr. = 0.02, t = 0.3).

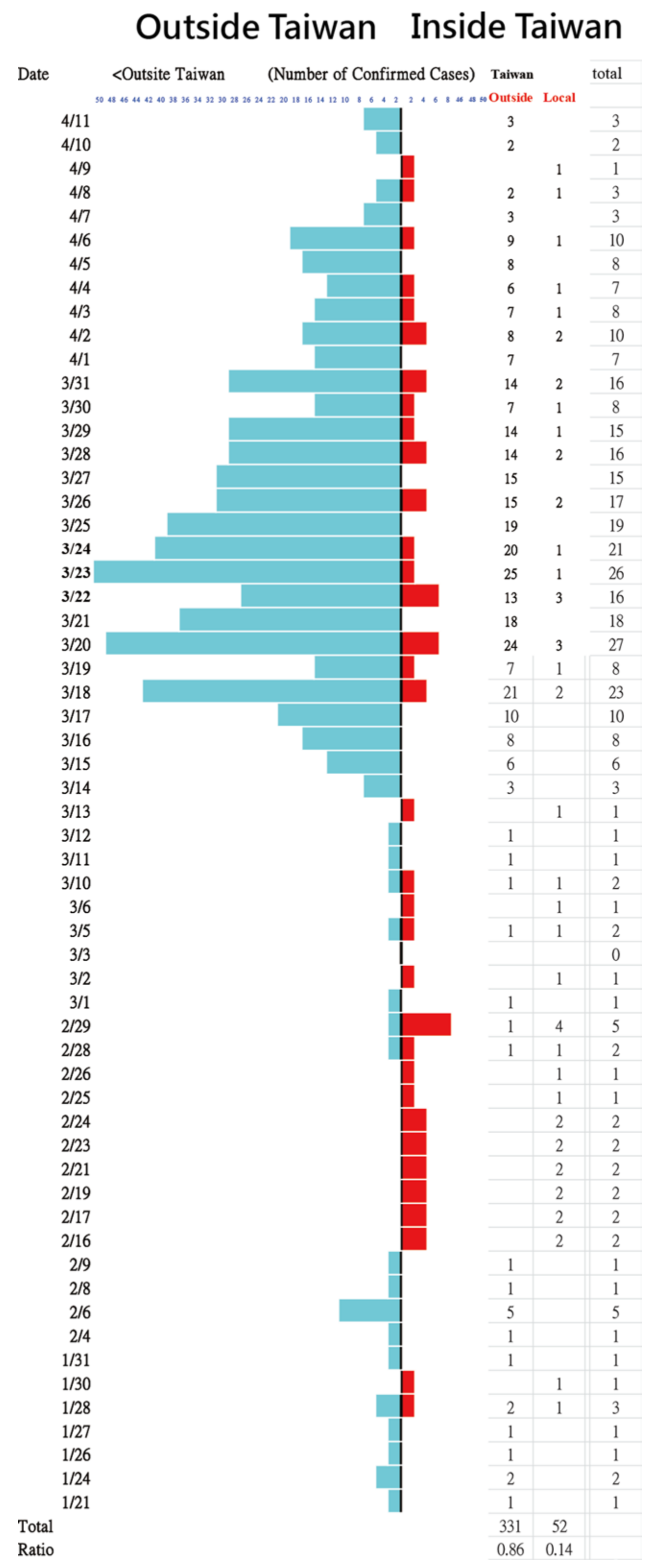

Figure 5. Comparison of confirmed cases from outside and inside Taiwan using the pyramid plot (Note: number of confirmed cases were from outside of Taiwan).

noncitizens from entering the country via China[15,49]; see the links[50,51] and Supplemental Digital Content 2, http://links.lww.com/MD/H342.

Moreover, Taiwan's health insurance system, which covers 99% of the country's population, has been praised. To prevent the spread of the outbreak, it is crucial to act quickly. Therefore, a system such as this allows everyone to receive the necessary medical treatment without incurring any financial burden, which is a burden when an infection is suspected.[52,53]

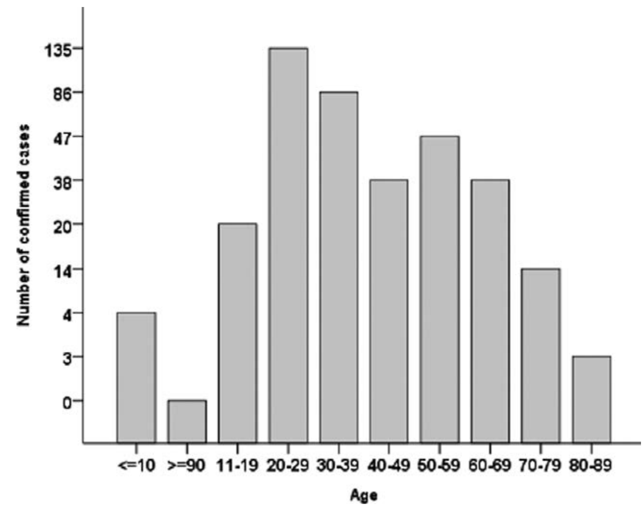

Figure 6. Distribution of confirmed cases for age groups in Taiwan (Note: the structure was affected more on the confirmed cased from outside of Taiwan).

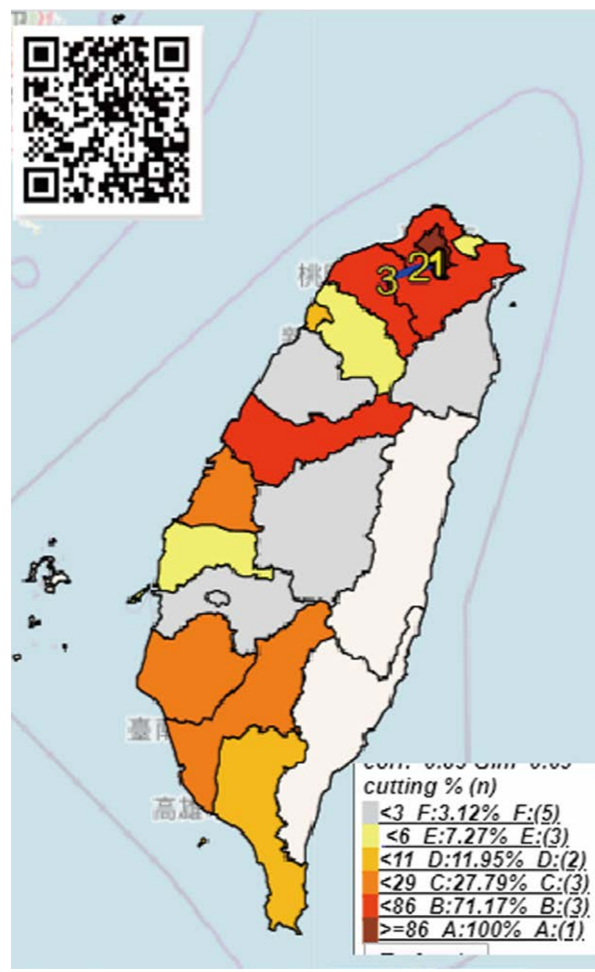

Figure 7. Distribution of confirmed cases across Taiwanese cities/counties (Note: The top 3 were from Taipei city, New Taipei city, and Taoyuan city due to the international airport located approximately 40 km (25 miles) west of Taipei in Dayuan District of Taoyuan city.

Vietnam has also been successful in containing the outbreak as a result of its early preparation from the first days of the pandemic.[11]

4.4. Strengths of this study

There are 3 key features of this study, which are highlighted below: CFR100 can be complementary to the deficit of traditional CFRs in epidemiology that does not consider population density; the one-dimensional category is verified with CC = 0.51 (t = 9.76) comprising 286 counts (11, 94, and 181), which makes comparing countries/regions on COVID-19 situations easier than ever before; and an app developed to display the CFR/CFR100 against TCC100 online[41,43,44] complements the traditional dashboards that do not consider population density.

In addition, numerous articles have been found in PMC that use the Kano model to report study results.[25–27] Using the Kano model, healthcare providers were able to improve the quality of their services.[26] As part of the evaluation of interventions to enhance the patient and family experience during pediatric sleep, the Kano Model was applied.[54] Correlation studies with scatter plots can also be used to display endogenous endogenous erythropoietin levels and electrocardiogram changes in patients with coronary heart disease and autonomic nerve damage.[55]

4.5. Limitations and future studies

Our study has several limitations. The first concern is that, even though the data were downloaded from Github[32] on a daily basis, the criteria used to determine confirmed cases may not be consistent throughout the world, which may have an impact on the CFR calculations. As an example, confirmed cases have been based on clinically diagnosed cases in Hubei since February 14, 2020.[56]

Second, although both CFR and TCC100 were applied to the dashboard (Fig. 4), the provisional CFRs were merely hidden behind their bubble sizes. In this case, a larger bubble indicates a higher CFR100, which might be complementary to the CFR in this case.

Third, although we recommend using a population-based method (e.g., CFR100 and TCC100 in this study), the traditional CFR cannot be ignored due to its familiarity with the general public, even though the density of the infected population is much higher than the total number of confirmed cases and CFR in nature.

Fourth, figures[41,43,44] illustrate dashboards on Google Maps. The Google Maps application programming interface requires a paid project key for the Google cloud platform, which makes these installments not free of charge. The limitation of the dashboard is that it is not publicly accessible, and it is difficult for other authors to emulate it within a short period of time.

Fifth, COVDI-19 data were derived on April 12, 2022, but the method of comparing TCC100 against CFR100/CFR on a Kano diagram holds merit for use in future epidemics (or pandemics).

Finally, every government has its own strategy and policy regarding COVID-19. Two examples were provided (e.g., Taiwan and Vietnam), where successful measures were taken to prevent outbreaks. There are many effective measures being taken to combat COVID-19, such as limiting human-to-human transmission, identifying, isolating, and providing optimal care for patients, and accelerating the development of diagnostics, therapeutics, and vaccines.[57] Furthermore, international, collaborative, and multisectoral approaches should be adopted to minimize social disruption and economic impact.

5. Conclusion

To better understand the COVID-19 pandemic, we illustrated TCC100 and CFR100 on a Kano diagram with bubble sizes. In contrast to the counterpart of the combination using TCC100 and CFR, there is a strong association between more TCC100 and CFR100. With the assistance of a dashboard laid over Google Maps, a mobile app was developed to display both TCC and CFR100 for countries/regions.

Author contributions

SY and YT developed the study concept and design. TWC, YT and WC analyzed and interpreted the data. WC monitored the process of this study and helped in responding to the reviewers' advice and comments. TWC drafted the manuscript, and all authors provided critical revisions for important intellectual content. The study was supervised by WC. All authors read and approved the final manuscript.
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Investigation: Willy Chou.
Methodology: Tsair-Wei Chien.

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