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Article

Evaluation and Prediction of the Covid-19 Pandemic Behavior and Evolution

Evaluación del comportamiento de la pandemia COVID-19 y pronóstico de su evolución

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ABSTRACT

Aim: to suggest indicators and procedures that assist in the evaluation and prediction of the behavior of COVID-19 pandemic, using basic mathematical knowledge.

Methods and techniques: search for information about the behavior of the pandemic in different scenarios, and the application of mathematical and statistical methods.

Main results: indicators and procedures that contribute to the evaluation of the situation caused by COVID-19, and the prediction of possible spikes of infected cases and deaths, to help in decision-making.

Conclusions: the indicators and procedures suggested contribute to the evaluation of the behavior of COVID-19 pandemic, and short and mid-term prediction of its behavior for decision-making by sanitary and government authorities.

Key words: COVID-19; health indicator; increase of daily infected cases; average increase; new lethality.

RESUMEN

Objetivo: Proponer indicadores y procedimientos para evaluar y predecir el comportamiento de la pandemia COVID-19 con el empleo de conocimientos elementales de matemática.

Métodos y técnicas: Búsqueda de información sobre el comportamiento de la pandemia en diferentes escenarios y aplicación de métodos matemáticos y estadísticos.

Principales resultados: Indicadores y procedimientos que contribuyen a evaluar la situación de la pandemia COVID-19 y hacer pronósticos en relación con el incremento de los contagios y defunciones para la toma de decisiones.

Conclusiones: Los indicadores y procedimientos propuestos contribuyen a evaluar el comportamiento de la pandemia COVID-19 y a predecir en el corto y mediano plazos su comportamiento para la toma de decisiones sanitarias y gubernamentales.

Palabras clave: COVID-19; indicador de salud; incremento diario de contagios; incremento promedio; nueva letalidad.

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INTRODUCTION

In situations generated by a special case as is the current pandemic, it is necessary to have indicators that help make decisions quickly, timely, and effectively, to prevent the collapse of the hospital system. For instance, in the case of Covid-19 the infected patient/daily discharges rate permits the evaluation of that possibility within the health care system; however, it does not facilitate the evaluation of tendencies and therefore, the prediction of future behaviors of the disease.

To conduct a far-reaching study of the behavior of the pandemic of Covid-19 caused by the novel coronavirus, in keeping with the health indicators suggested by the Pan-American Health Organization (PAHO, 2018). The purpose of this paper is to suggest two health indicators and procedures, using basic mathematical knowledge to evaluate and predict the behavior of the pandemic of Covid-19. One of them is the daily increase of contagions associated with indicator health care services; the other is an alternate way of calculating lethality associated with the indicator of mortality. Other indicators derive from the previous.

The daily increase of contagions can be used to calculate the average daily increase of contagions of a particular period, and determine the confidence intervals, which enable researchers to predict the future behavior of the disease.

The daily lethality data are relative in that the individuals diagnosed on a day or in previous days have not had time to evolve into recovery or a fatality. The number of days in which the high percent of positive cases decide their definitive evolution must be considered. The above suggests another way of calculating lethality. In face of the question What is the true lethality? a relative error consisting in the acceptance of one or the other can be introduced.

The paper is structured as follows: it defines the daily increase of contagions (IDC), the average increase of contagions (IPC), and the way of determining the number of contagions after N days starting on a given day, both in specific points and by intervals. Then the study shows how to estimate the number of days that must elapse to reach a given figure of contagions, which is identical in the case of deaths. The daily increase of deaths (IDD) and the average increase of deaths (IPD) are defined the same way, with a similar way of conducting the calculations. Finally, the new lethality can be defined, and its convergence with the official lethality is presented, which leads to the introduction of the error of accepting one or the other.

DEVELOPMENT

Statistical indicators

One of the challenges of governments today is to rely on relevant and timely information to make decisions; indicators are naturally, a tool that supports the ability of decision-makers in governments and other areas. The utilization of information during decision-making has a relevant role, and statistical indicators are, undoubtedly, a tool to conduct such actions (Godin, 2003).

An indicator is a measurement of a given situation. Every health indicator is an estimation (a measurement with certain degree of inaccuracy), of a particular dimension of health care in a specific population (PAHO, 2018). Other authors and institutions refer to the term in an analogous way, namely, PAHO (2014), the United Nations (2014), Oliva, Delgado, and Larrauri (2019), and Walker, Whittaker, Watson, and Baguelin (2020).

However, one of the most widely used definitions by several bodies and authors is the one provided by Bauer in 1966 (cited by Mondragón, 2002, p.52): “The social indicators (...) are statistics, statistical series or any form of indication that helps us study where we are, and where we are headed in relation to certain goals and objectives, and to evaluate specific programs and determine their impact”.

There are other definitions given by other authors, such as the one given by Campistrous and Rizo (2008), who state that “It is a variable that enables the indication of values from another variable; that is, its values indicate the values of another variable” (p. 2).

The previous definitions are necessary to achieve the aim of this research, since the indicators suggested show the values of another variable associated with the behavior of the Covid-19 pandemic in the world, in keeping with the goals suggested.

Now, the authors of this study suggest a set of indicators and procedures that can be used in decision-making.

Daily increase of contagions

The number of the daily increase of contagions is defined as the quotient between the number of infected individuals that day and the total accumulated number of contagions from the previous day, namely IDC.

The formula is $IDC = \frac{\textit{Number of contagions on a day}}{\textit{Accumulated contagions until the previous day}}$ (1)

The IPC in N days is given by the sum of IDC of the days included, divided by N, using the formula: $IPC = \frac{\sum_{i=1}^{n} IDC_i}{n}$ (2)

The accumulated number of contagions on the Nth day on a given day can be estimated in two ways:

First: punctually, a case $C_n = (1 + IPC)^n C_i$ (3) where C_n is the expected number of accumulated contagions on the Nth day, from the number of accumulated contagions on the initial or start day C_i, n is the number of days and IPC is the average increase of contagions in the last 10 days. Other ideas can be considered, but possibly, the trend becomes remarkably different. See Table 1.

This estimation does not permit prior knowledge about the reliability of the result, as observed with the estimation of the interval below.

A confidence interval of this IPC type, with an unknown variance (90% confidence) takes place as a result of $\left]IPC - \frac{s}{\sqrt{n}}\, t_{0.95}^{(n-1)} ; IPC + \frac{s}{\sqrt{n}}\, t_{0.95}^{(n-1)}\right[=]IPC_i ; IPC_d[$ (4), where $s = \frac{1}{n}\left(\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}\right)$ (5) is the typical deviation and $t_{0.95}^{(n-1)}$ refers to the distribution by T Student.

To provide a confidence interval that helps predict the accumulated contagions from a particular day (C_i), for N days after (C_n), first, the interval is determined $](1 + IPC_i)^n ; (1 + IPC_d)^n[$ (6), and then, the expected interval is multiplied by C_i both ends $](1 + IPC_i)^n C_i ; (1 + IPC_d)^n C_i[$. (7) $C_n = (1+ IPC)^n C_i$, (3) is the basic formula for both estimates (Cué, Castell, and Hernández, 1987).

Note: All the dates shown from now on were collected in 2020 from the records of the Ministry of Public Health (2020).

It can be said that based on the average increase of contagions in the world on May 11-20, including both, as shown in Table 1, $IPC = 0.020\ 2,$ calculating the data from the official site of the Ministry of Public Health (2020), with a typical deviation of s $=0.001\ 536$.

The confidence interval of IPC is $]0.019\ 3 ; 0.021\ 09[$, from which the interval (4) of 5, 10, and 15 days is determined. The intervals are obtained by

$I_5 =]1.100\ 35\ ;1.109\ 99[$

$I_{10} =]1.210\ 77\ ;1.232\ 08[$

$I_{15} =]1.332\ 27\ ;1.367\ 6[$,

Now, multiplying each group at the end of previous intervals by $C_i = 476\ 646\ 8$ as indicated in the interval (6) that corresponds to the accumulated contagions on May 20th, the corresponding confidence intervals are obtained (6) from the accumulated contagions on May 25th and 30th, and June th.

$I_5 =]5\ 244\ 783\ ;5\ 290\ 731[$ *compared to a real of* $5\ 273\ 572$

$I_{10} =]5\ 771\ 096\ ;5872669[$ *compared to a real of* $5\ 776\ 934$

$I_{15} =]6\ 350\ 222\ ;6\ 518\ 621[$ *compared to a real of* $6\ 348\ 900$

The relative theoretical error of the interval $[a;\ b]$ is given by $e_t = \frac{b-a}{a+b}$ (8) that results from the division of half of the interval length between the value of its midpoint. It usually is expressed in percent.

The real relative error of the interval $[a;\ b]$ is given by $e_r = \frac{|2r-a-b|}{r}$ (9) that results from the division the modular difference between the real value and the midpoint of the interval by the real value. It usually is expressed in percent.

The relative theoretical and real errors introduced by taking the midpoint of the interval as the accumulated contagion value are,

$e_{5t} = 0.44\%$ and $e_{5r} = 0.11\%$

$e_{10t} = 0.87\%$ and $e_{10r} = 0.78\%$

$e_{15t} = 1.31\%$ and $e_{15r} = 1.35\%$, t and r indicate a theoretical or real error; the numbers correspond to the number of days considered.

When the same analysis is performed in the Americas during the same period, the results were as follows: $IPC = 0.0235$, $s = 0.003\ 612$

The confidence interval of IPC is $]0{,}021\ 41\ ;\ 0{,}025\ 59[$ and the auxiliary intervals for the calculation of confidence intervals are,

$I_5 =]1{,}111\ 73\ ;\ 1{,}134\ 66[$

$I_{10} =]1{,}235\ 95\ ;\ 1{,}287\ 47[$

$I_{15} =]1{,}374\ 04\ ;\ 1{,}460\ 85[$

From which the corresponding confidence intervals occur for the days mentioned before.

$I_5 =]\ 2\ 372\ 937\ ;2\ 421\ 880\ [$ compared to a real of 2 419 355

$I_{10} =]\ 2\ 638\ 079\ ;27\ 48\ 046\ [$ compared to a real of 2 698 519

$I_{15} =]\ 2\ 932\ 826\ ;3\ 118\ 118\ [$ compared to a real of 3 019 104

The corresponding relative errors are,

$e_{5t} = 1.02\%$ and $e_{5r} = 0.91\%$

$e_{10t} = 2.04\%$ and $e_{10r} = 0.20\%$

$e_{15t} = 3.06\%$ and $e_{15r} = 0.21\%$

In general, it is better to have real errors than theoretical errors, as can be seen. In the Americas, the results are more favorable; they may obey to the fact that the mean increase of contagion in this region during the following 15 days coincided with the previous period. In the world, the previous period was 0.020 2 with 0.019 3 in the next 15 days (Table 1), including accumulated errors by chance when the daily increases were approximated. This happens despite the greater variability in the behavior of this indicator in the Americas (within the period studied). Note that the variation coefficient in the Americas is 15.37%, whereas the world is 7.60% during the same period.

The following is an illustration of Cuba. The data were collected from the site of the Ministry of Public Health (2020):

The IPD during the first 16 days of September was approximately 0.009 4. The application of the suggested procedure was thought to produce an accumulated death of 124 at the end of the month; the real was 28 people, instead of the 30 predicted for this month. In relative terms, the error is insignificant, but in absolute terms, it is important because every life counts. The dedicated work of the health staff and timely decisions saved two lives.

The average increase of contagions in the last third of September was 0.95%, and the lethality error varied between a minimum of 12.8% and a maximum of 16.1%, with a decreasing tendency since September 22nd, though still high. These parameters do not point to control; however, this analysis can be applied to different territories (provinces or municipalities), and use other indicators to check where there is a real tendency toward control.

Table 1 shows the behavior of IPC in same periods of the pandemic and in different scenarios.

Table 1. Behavior of the average contagion increase in some periods and scenarios

Period	World	The Americas	The USA	Cuba
5/1–10	0.024 8	0.030 5	0.022 0	0.016 8
5/11-20	0.020 2	0.023 5	0.017 0	0.007 3
5/21-30	0.019 3	0.023 9	0.015 9	0.006 4
6/11-20	0.018 1	0.020 6	0.010 3	0.004 4
6/21-30	0.017 9	0.021 5	0.014 9	0.001 3
7/1–10	0.017 4	0.020 1	0.017 7	0.003 1
7/11-20	0.017 4	0.018 0	0.018 9	0.001 1
7/21-30	0.015 9	0.017 0	0.020 5	0.004 8
Mean	0.018 9	0.021 9	0.017 2	0.0056 5
Typ. Dev.	0.002 546	0.003 929	0.003 297	0.00046 9
VC	13.49%	17.95%	19.19%	8.29%

Source: Calculation based on data published at the official site of the Ministry of Public Health (2020) of Cuba

The behavior of the increase of contagions did not show a stable growth, with ebbs and flows. Although the moment following that in the table does not show higher figures above the mean of every scenario, greater increases were recorded in relation to the lowest average increases, therefore, without a trend to decrease in the short run.

The above is valid in the rise of deaths, which is calculated similarly, using every formula and procedures described with the corresponding changes in data inputs.

All the above is valid to calculate IDD, IPD, and the corresponding confidence intervals and their errors.

It offers possibilities of determining the daily increase of contagions, the average increase, the estimation of the number of contagions in the mid and short runs, and the evaluation of the error made. It can be done similarly in the case of deaths.

Estimation of the number of days needed to reach a particular figure of contagions or deaths

The previous item described how to calculate the number of contagions or deaths of a number of days. Here the objective is to achieve the opposite: to learn how many days are needed to reach a particular number of contagions or deaths. Accordingly, the authors used the following expression resulting from the general formula (3), taking the logarithm of the two members and performing the necessary changes and adjustments.

$$n = \frac{Ln\,\frac{C_n}{C_i}}{Ln\,(1+IP)} \quad (10)$$

It permits the authors to know the number of days when a preset figure of contagions or deaths can be reached, given by C_n, based on the current figure, given by C_i and the average daily index of contagions or deaths, depending on the particular cases, given by IPC. For instance, between August 1st and 11th, (10 days) the world's IPD was 0.007 527 approximately; on August 11th the accumulated number of deaths was 731 263, with the intention of learning when the death toll would reach the million, assuming that the same tendency would continue.

In $n = \frac{Ln\,\frac{D_n}{D_i}}{Ln\,(1+IPD)},\ D_n = 1\,000\,000,\ D_i = 731\,263\ e\ IPD = 0.007\,527$

Hence, within 42 days the world would reach the million deaths, on September 22nd.

The new lethality and the official lethality

The Pan American Health Organization (PAHO, 2018) defines indicators of mortality as "The data of mortality represent a fundamental source of demographic, geographic, and death-related information. These data are used to quantify health problems, and to determine or monitor health priorities or goals" (p. 9). A closely-related lethality-mortality link.

The proposal of a new lethality can warn about what will occur eventually, and may be valuable for decision-makers to design strategies in a post-pandemic setting, help evaluate the results of treatments applied in different moments, etc.

It consists in dividing the number of accumulated deaths by number of accumulated contagions 14 days before (this figure is used as basic).

Both lethality types have been dropping with the passing of the pandemic, and tend to converge. Below, Tables 2, 3, 4, and 5 show examples of the behavior, using various scenarios.

Table 2. Behavior of lethality and error in the USA

Date	Official lethality	Suggested lethality	Error (%)
April 27th	5.14	9.37	45.1
May 12th	6.05	8.00	24.4
May 18th	6.09	7.85	22.4
May 25th	5.99	7.54	20.6
June 4th	5.84	6.82	14.4
June 11th	5.68	6.78	16.2
July 3rd	5.69	6.75	15.7
July 10th	4.40	5.62	21.7
July 30th	3.46	4.41	21.54

Source: Calculation based on data published at the official site of the Ministry of Public Health (2020) of Cuba

Table 3. Behavior of lethality and error in the world

Date	Official lethality	Suggested lethality	Error (%)
April 30th	7.09	11.11	36.18%
May 7th	7.09	10.19	30.42%
May 14th	6.90	9.31	25.89%
May 21st	6.63	8.90	25.51%
June 1st	6.12	8.02	23.69%
June 12th	5.67	7.21	21.36%
June 24th	5.20	6.67	22.04%
July 11th	4.53	5.79	21.76%
July 30th	3.95	4.96	20.36

Source: Calculation based on data published at the official site of the Ministry of Public Health (2020) of Cuba

Table 4. Behavior of lethality and error in the Americas

Date	Official lethality	Suggested lethality	Error (%)
April 30th	5.67	10.00	43.30%
May 7th	5.83	9.25	36.97%
May 14th	6.00	8.56	29.91%
May 21st	5.93	8.35	28.98%
June 1st	5.67	7.88	28.05%
June 12th	5.41	7.15	24.34%
June 24th	5.00	6.65	24.81%
July 11th	4.37	5.81	24.78%
July 30th	3.85	4.93	21.91%

Source: Calculation based on data published at the official site of the Ministry of Public Health (2020) of Cuba

Table 5. Behavior of lethality and error in Cuba

Date	Official lethality	Suggested lethality	Error (%)
April 30th	4.06	7.08	42.66
May 7th	4.22	5.91	28.60
May 14th	4.32	5.26	17.87
May 21st	4.19	4.63	9.50
June 1st	3.98	4.41	9.75
June 12th	3.76	4.15	9.40
June 24th	3.67	3.81	3.67
July 11th	3.60	3.73	3.49
July 30th	3.35	3.57	6.16

Source: Calculation based on data published at the official site of the Ministry of Public Health (2020) of Cuba

Mathematically, the convergence of the two lethality types can be explained. Accordingly, the following variables are defined.

D_i: Accumulated deaths on day i

C_i: Accumulated contagions on day i

I_{pi}: Increase index on day i

LO_i: Official lethality on day i

LN_i: New lethality on day i

$LO_i = \frac{D_i}{C_i}$ (11), $LN_i = \frac{D_i}{C_{i-14}}$ (12)

The expression $C_i = C_{i-14}\,(1 + Ip_i)^{14}$ (13) yields $C_{i-14} = \frac{C_i}{(1+Ip_i)^{14}}$ (14)

From which $LN_i = \frac{D_{i\,(1+Ip_i)^{14}}}{C_i}$ (15) results when $Ip_i \to 0, LN_i \to LO_i$

When assessing the behavior of the pandemic both indicators should be together; the daily increase of contagions not only represents a decrease in the trend, it must be quite lower than 1%, and at the same time, the error must near zero.

For example, in Cuba, in the June 2nd-July 21st period, the average daily increase index was 0.31%. On June 2nd, the official lethality was 3.97%, whereas the new lethality was 4.37%, with an error of 9.15%. On July 21st, the official lethality was 3.55%, whereas the new lethality was 3.63, producing an error of 2.20%, a period when everything leaned toward control. Since then, a rising trend began, though variable during the first days, but on July 26th the tendency was clearly rising up to 14.08%, on August 8th. In the same

lapse, the daily increase index skyrocketed in relation to the previous behavior, reaching higher figures above 1%, with a highest peak on August 7th, with 1.73%. A period when events caused by the lack of compliance with the regulations, complicated the situation.
In the other scenarios studied, the daily increase of contagions was generally above 1%, and though the errors showed a tendency toward a decrease, it was slow, with more than 15%, which indicates that there is no control of the pandemic yet.

CONCLUSIONS

The indicators established were the daily increase of contagions and deaths, which derived into the corresponding average increases and new lethality, which derives into the relative error that occurs when accepting one or the other. This indicator, along with the daily increase of contagions showed the evolution of the pandemic. These indicators are not intended to replace others, but to complement them and offer other angles of the problem. Moreover, the procedures to calculate figures of contagions and deaths on a particular day, and to establish the number of days in which certain levels of contagions or deaths can be reached.
The indicators and procedures suggested permit short and mid-term predictions of total contagions and deaths, becoming an important tool for decision-making by sanitary and government authorities that ensure a logistic to prevent the collapse of sanitary systems and necrological systems, and to favor better patient care.

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Conflict of interest and conflict of ethics statement

The authors declare that this manuscript is original, ans has not been submitted to another journal. We are responsible for the content published in this paper, and certify the existence of no plagiarism, or interest or ethical conflicts.

Authorship statement

Giordano Rodríguez Rodríguez. Leader, theoretical rationale, design of indicators, procedures, and tools for analysis.

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Rafael F. Ramírez Varona. Manuscript design, redaction of the results, abstract, review of contents.
Magaly Almeida Borges. Redaction and review of contents.