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COVID-19 Double-Decrement Model Forecasting for South Korean Population

Christian Evan Chandra [a], Sarini Abdullah [a,*]

[a] *Department of Mathematics, University of Indonesia, Kampus Baru UI, Depok, 16424, Indonesia*
*Corresponding author: *sarini@sci.ui.ac.id*

***Abstract*—Since the first case in November 2019, COVID-19 has spread fast, infected many people, and taken many lives. Once COVID-19 cases are confirmed, and hospital treatments are required, they will need high costs yet still be at risk of death. Therefore, insurance companies and social service providers need a reliable model to estimate the expenses and ensure their financial health. This study discusses the modeling of time-until-release and time-until-death since cases are confirmed, using the South Korean data. Double-decrement model is assumed to follow Weibull and log-logistic hazard for time-until-release and time-until-death, respectively. Considered risk factors are sex, symptoms, age group, and the month when the case is confirmed. The nonlinear survival regression model is proposed, with the Solver function in Microsoft Excel for parameter estimation. The results suggest that virus lifespan and mortality risk get lower over time. Time-until-death is also lower, implying that we have less time to save lives from mortality risk. More frequent testing with faster results and not waiting for the symptoms to occur is needed for people under thirty years old due to shorter time-until-death and those at sixty and above due to higher case fatality rates. Full dose vaccination must be prioritized for ages sixty and above to save as many lives as possible.**

***Keywords*— Pandemic modeling; survival regression; time series modeling.**

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I. INTRODUCTION

Coronavirus disease (COVID-19) tends to be a very worrying disease all over the world. The earliest case was detected on November 17, 2019, in Wuhan [1], and the first imported case was found in Thailand on January 13, 2020 [2]. In the beginning, some parties put optimistic about fighting against it. Indonesian airline industries offered significant price rebates for flight tickets [3], and insurance companies in the United States agreed to waive co-pays and extend coverage for COVID-19 treatment [4].

As the disease spread fast in both local and international transmissions [5], people did self-quarantine and self-isolation to prevent themselves from getting infected. Students and workers did their activities from home. However, as the economy struggled, countries started to have a "new normal" situation to keep it running as long as a society keep to wear its masks [6]. For example, Health Service Executive in Ireland, that initially suggested people have themselves at home unless they were working for essential services [7], changed their opinion that self-isolation is only needed for someone with symptoms or a positive test result for coronavirus. They also convince readers that most of coronavirus cases will only have mild symptoms and get well within weeks. Therefore, people go out from home not only to earn a living, but also fulfil their longing satisfaction to have physical shopping activities while social distancing is still performed [8]. Even some countries permit their citizens to stop wearing a mask after getting fully vaccinated [9].

The third wave of COVID-19 is unavoidable, bringing countries back to struggling conditions [10]. It was reported that survivors have a continuous impact on cognitive and functional decline, even though they only had mild symptoms [11]. As COVID-19 cases increase and lots of patients need treatment [12], it is important to make sure that early detection [13] and contact tracing procedure [14] are conducted effectively to prevent rapid transmissions.

Several studies learned about the length of stay by COVID-19 patients in the hospital [15], even with further examination of the length of stay in intensive care units [16], [17] considering the related risk factors [18]–[20]. When countries continuously calculate the case fatality rate, another scientific study also learned about time to death in COVID-19 cases [21], [22] and the related risk factors [23], [24]. The effect of age and gender on COVID-19 recovery is studied by Voinsky et al. [25]. Nonetheless, we have not found a study that modeled these three factors together: time to recovery for survivors, time to death for non-survivors, and recovery rate. Therefore, we propose developing a model that considers these factors.

In this study, we construct a double-decrement model and also forecast if the COVID-19 condition is improving or getting worse in the future. The rest of this paper is organized as follows. Section 2 describes the procedure of data pre-processing and model construction. Section 3 discusses our results with further analysis in proposing proper handling. Finally, Section 4 provides a conclusion of this study.

II. MATERIALS AND METHODS

In this section, we explain the data that is used for this study. We also describe how we pre-process the data and conduct explanatory data analysis of the cleaned data. Furthermore, we construct our double-decrement model using assumptions based on parametric statistical distributions.

A. *Data Source and Preprocessing*

We analyzed the patient information part of Data Science for COVID-19 dataset [26], which was last updated on July 01, 2020. Newer open-access data sources are not found, possibly due to privacy issues [27]. The dataset consists of 5,165 patient records in South Korea, with the first confirmed case, release from the hospital as a survivor, and death recorded on January 20, February 05, and February 19, respectively. We have information on the patient's ID, sex, age group (in the multiple of ten), origin country, city, and province where the patient was detected as a COVID-19 case, infection case, infecting agent, symptom onset date, and description (if any), confirmed date, released or deceased date (if any), and state where the case occurs. However, we limited our scope of risk factors only to consider the sex, age group, symptom binary indicator, and the month when the case was detected. We found several cases with incomplete data and deleted them, leaving 2,838 cases to be analyzed.

B. *Exploratory Data Analysis*

We calculated the duration since being confirmed as a COVID-19 case until either the release date (if the case is released as a survivor), death date (if the case is deceased), or the last update date (if the case is still isolated at the observation time). This study suggests that most cases occurred without symptoms, so suggestions to only have self-isolation when an individual feels symptoms are considered inappropriate. More females contracted COVID-19 than males, and significant age groups impacted are 20s until 60s. The number of monthly cases initially grew fast from January until March of 2020, then slowly decreased from April until June 2020. Median and mean waiting times from being confirmed as a COVID-19 case until released as a survivor are 23.00 and 24.82 days, respectively. However, its standard deviation is 13.01 days, implying that the waiting time mostly varied within around two weeks shorter or longer than the mean. It is also worth noting that 75% of cases still in isolation have been in hospital for more than 44 days.

C. *Double-Decrement Model Construction*

In this study, we only consider time-until-recovery between the detection date and recovery date for the same occurrence of COVID-19. When a subject is exposed to COVID-19 more than once, the time-until-recovery is measured on each exposure. Moreover, death is surely an absorbing state. Therefore, recovery (which is represented by being released from the hospital as a survivor) and death are decremented. The model that we are going to construct is a double-decrement model. According to [28], our model has two random variables. The first one is time-until-event for a confirmed case who is on day x of his/her treatment in the hospital, denoted as T(x). Then, we also have the cause of decrement to be denoted as J(x). In this study, J(x) = 1 if the case is released from the hospital as a survivor or 2 if the case is deceased in the hospital. We have to construct our force of decrement due to cause 1 and cause 2, so the overall model fulfills the characteristics of a survival model.

By limiting the population to all cases which were already deceased, we plotted their empirical density function of T (0) in Figure 1. It is seen that the density is hump-shaped, and this fact is appropriate for some medical explanations. Severe cases started the crisis about five to eight days after symptoms began because of shortness of breath and acute respiratory distress syndrome when the situation is called a second-week crash [29]. However, as most cases are considered mild, we also need to cater to the alternative case in the model in that the density distribution is as simple as decreasing over time.

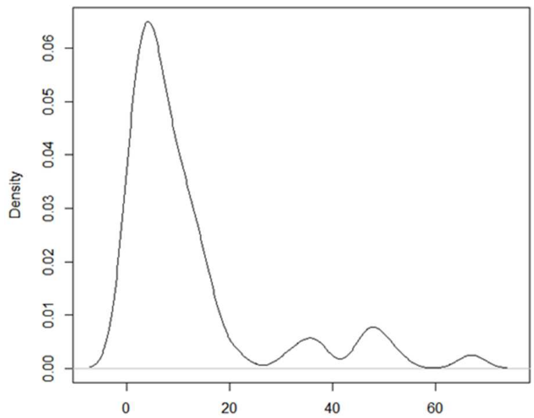

Fig. 1 Density plot of empirical T(0) values, given the case, was finally deceased.

After considering the tractability of the related functions, we choose log-logistic distribution as the baseline to assume the absolute incidence of death. According to Klein and Moeschberger [30], we define the force of decrement at day t due to cause 2 and net probabilities of decrement up to day t due to cause 2 given the case is in day 0 of his/her treatment as (1) and (2), respectively.

$$\mu_t^{(2)} = \frac{\alpha_2 \lambda_2 t^{\alpha_2 - 1}}{1+\lambda_2 t^{\alpha_2}} \quad (1)$$

$$_{t}q'^{(2)}_{0} = 1 - \frac{1}{1+\lambda_2 t^{\alpha_2}} \quad (2)$$

By limiting the population to all cases already released as survivors, we also found a hump-shaped density function for the empirical distribution of T(0) as depicted in Figure 2. However, we consider this condition more due to the lack of cases requiring long recovery time to be released.

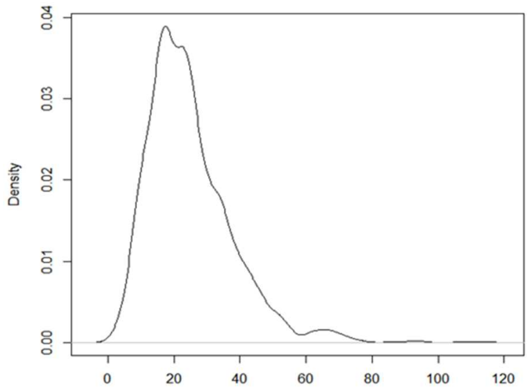

Fig. 2 Density plot of empirical T(0) values, given the case, was released as a survivor.

There are two possible scenarios of time-until-recovery distribution. The first scenario is that most cases of COVID-19 need a short time to be recovered, and those who need a long time are considered special cases because of lower immunity levels than the population average. Therefore, the hazard rates must be decreasing or constant over time, and the density function must decrease over time. While the second scenario is the opposite, most cases of COVID-19 need longer to be recovered and those who need shorter time are considered special cases because of higher immunity levels than the population average. Therefore, the hazard rates must increase over time, and the density function is hump shaped.

We choose Weibull distribution as our baseline to assume the absolute incidence of releases as survivors. According to Klein and Moeschberger [30], we define the force of decrement at day t due to cause 1 and net probabilities of decrement up to day t due to cause 1 given the case is in day 0 of his/her treatment as (3) and (4).

$$\mu_t^{(1)} = \alpha_1 \lambda_1 t^{\alpha_1 - 1} \tag{3}$$

$$_tq'^{(1)}_0 = 1 - e^{-\lambda_1 t^{\alpha_1}} \tag{4}$$

As the sole force of decrement is equal to the force for that decrement in the multiple decrement model, we could construct overall function that the COVID-19 virus still resides in the living body given the case is in day 0 of his/her treatment as (5).

$$_tp_0^{(\tau)} = \frac{e^{-\lambda_1 t^{\alpha_1}}}{1+\lambda_2 t^{\alpha_2}} \tag{5}$$

Values of the distribution parameters, α_1, α_2, λ_1, λ_2, must be positive. We assumed that the effects of sex (x_1) and symptoms (x_2) are proportional to the parameters. On the other side, the effects of age group representation (x_3) and month representation (x_4) are quadratic on the logarithm of the parameters. It is important that we record the information so the value of x_3 equals floor of case's age divided by ten, is written mathematically as $\left\lfloor \frac{\text{age}}{10} \right\rfloor$. January 2020 is the starting point of the data, and having the value of x_4 equals zero. Next, x_4 equals one, two, three, and so on for February 2020, March 2020, April 2020, and further months. Therefore, formulas for the parameters in terms of the regressors are provided as (6) to (9).

$$\alpha_1 = \alpha_{1,0}\exp(\alpha_{1,1}x_1 + \alpha_{1,2}x_2 + \alpha_{1,3}x_3) \times \exp(\alpha_{1,4}x_3^2 + \alpha_{1,5}x_4 + \alpha_{1,6}x_4^2) \tag{6}$$

$$\alpha_2 = \alpha_{2,0}\exp(\alpha_{2,1}x_1 + \alpha_{2,2}x_2 + \alpha_{2,3}x_3) \times \exp(\alpha_{2,4}x_3^2 + \alpha_{2,5}x_4 + \alpha_{2,6}x_4^2) \tag{7}$$

$$\lambda_1 = \lambda_{1,0}\exp(\lambda_{1,1}x_1 + \lambda_{1,2}x_2 + \lambda_{1,3}x_3) \times \exp(\lambda_{1,4}x_3^2 + \lambda_{1,5}x_4 + \lambda_{1,6}x_4^2) \tag{8}$$

$$\lambda_2 = \lambda_{2,0}\exp(\lambda_{2,1}x_1 + \lambda_{2,2}x_2 + \lambda_{2,3}x_3) \times \exp(\lambda_{2,4}x_3^2 + \lambda_{2,5}x_4 + \lambda_{2,6}x_4^2) \tag{9}$$

We implemented maximum likelihood estimation to estimate the regression parameters. The likelihood for a case that is still in isolation (denoted as $L_{o,t}$), released as a survival (denoted as $L_{1,t}$), and deceased (denoted as $L_{2,t}$), each in day t, are written as (10) to (12), respectively. In the end, the overall likelihood function is obtained by multiplying the likelihood for each case.

$$L_{0,t} = \frac{e^{-\lambda_1 t^{\alpha_1}}}{1+\lambda_2 t^{\alpha_2}} \tag{10}$$

$$L_{1,t} = \frac{e^{-\lambda_1 t^{\alpha_1}}}{1+\lambda_2 t^{\alpha_2}} \alpha_1 \lambda_1 t^{\alpha_1 - 1} \tag{11}$$

$$L_{2,t} = \frac{e^{-\lambda_1 t^{\alpha_1}}(\alpha_2 \lambda_2 t^{\alpha_2 - 1})}{(1+\lambda_2 t^{\alpha_2})^2} \tag{12}$$

The Solver function estimated regression parameters in Microsoft Excel 365 Version 2006, similar software also used by Mishra et al. [31]. As the value of likelihoods is too small for computation, we prefer to maximize the overall loglikelihood function [32]. Summary of the methodology is depicted in Figure 3.

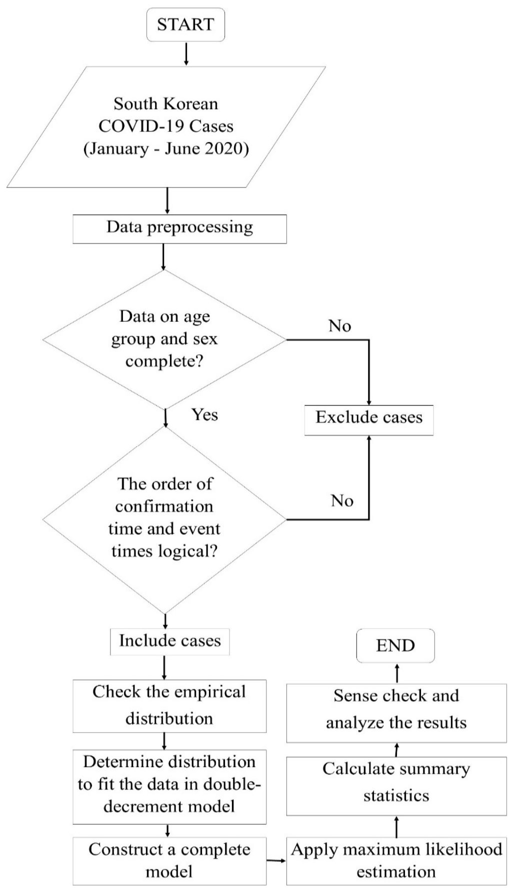

Fig. 3 Research flowchart

III. Results and Discussions

In this section, we forecast some summary statistics for the period July, August, and September 2020 based on the fitted model since our data coverage period ended in June 2020. In order to get the parameter estimates, we implemented two steps of the evolutionary method and three steps of Generalized Reduced Gradient (GRG) nonlinear method to achieve the value of the overall loglikelihood function at -3791.41.

A. Virus Lifespan

We do not have a certain limit on the lifespan of COVID-19 in human's body, so it is plausible to assume that the virus might last forever. However, at the population level, we only have to ensure that most of the COVID-19 cases who are released from the hospital as survivors are noninfectious anymore. Therefore, ignoring the cause of decrement, we forecast the mean of COVID-19 lifespan given that the individual does not feel any symptoms before being confirmed as a case in July, August, and September 2020, and it is not known then he/she will survive or decease. The result is presented in Table I. For the next months after September, the values are convergent to one for all age groups. M stands for male, and F stands for female.

TABLE I
MEAN FOR VIRUS LIFESPAN (IN DAYS)

Age Group	July 2020		August 2020		September 2020	
	M	F	M	F	M	F
0 – 9	6.83	6.84	2.01	2.01	1.19	1.20
10 – 19	6.73	6.73	2.00	2.00	1.19	1.19
20 – 29	6.63	6.63	1.99	1.99	1.19	1.19
30 – 39	6.53	6.53	1.98	1.98	1.19	1.19
40 – 49	6.44	6.44	1.97	1.97	1.19	1.19
50 – 59	6.34	6.35	1.95	1.96	1.19	1.19
60 – 69	6.23	6.24	1.87	1.87	1.14	1.14
70 – 79	5.26	5.35	1.63	1.63	1.11	1.10
80 – 89	5.64	5.73	1.71	1.70	1.12	1.11
90 – 99	5.98	5.99	1.89	1.89	1.17	1.17

Although the lifespan of COVID-19 is decreasing over time, we still need to look at the possible worst case. When a newer variant comes, a wave of morbidity risk gets to be restarted as it takes time for scientists to understand its characteristics. It is also possible that medicines and vaccines considered effective for previous variants might not be effective for the newer variant. Recently longest COVID-19 case reported by Morrison [33] is not surprising for us, considering that our fitted 99-percentile of virus lifespan in April is 964 days for them with symptoms and 850 days without any symptoms.

B. Mortality Risk

We are also interested in calculating the case fatality rates for cases who do not feel symptoms before being confirmed as COVID-19 infected, as served in Table II. In order to keep efficiency in presenting the numbers:

- numbers less than 10^{-5} are noted as "<<<",
- numbers greater than or equal to 10^{-5}, but less than 10^{-3} are noted as "<<",
- numbers greater than or equal to 10^{-3}, but less than 10^{-2}, are noted as "<", and
- otherwise, it will be presented in percentages.

It suggests that, case fatality rates are increasing in age and decreasing in time. The mortality risk is considered significant for ages 60 – 89 in all three months, assuming 1% significance level. The further calculation not shown here shows that the fitted case fatality rate for those who feel symptoms is always lower for all age groups from January 2020 – September 2020. An explanation of this situation might be that the clinician is more aware of symptoms, so an effort is put to heal the patients. While, when there are no symptoms, no precautionary actions were taken; thus, the patients were not realized to have a higher mortality risk. M stands for male, and F stands for female.

TABLE II
CASE FATALITY RATES

Age Group	July 2020		August 2020		September 2020	
	M	F	M	F	M	F
0 – 9	<<<	<<<	<<<	<<<	<<<	<<<
10 – 19	<<<	<<<	<<<	<<<	<<<	<<<
20 – 29	<<<	<<<	<<<	<<<	<<<	<<<
30 – 39	<<<	<<<	<<<	<<<	<<<	<<<
40 – 49	<<<	<<<	<<<	<<<	<<<	<<<
50 – 59	<<<	<<<	<<<	<<<	<<	<<
60 – 69	4.1%	2.9%	64.4%	68.2%	99.8%	99.9%
70 – 79	72.5%	70.1%	99.5%	99.6%	99.9%	99.9%
80 – 89	45.7%	40.5%	96.7%	97.2%	99.9%	99.9%
90 – 99	<	<	<	<	10.3%	14.3%

Although the results in Table I and Table II do not indicate the significance of infection duration and mortality risk, we should look for time-until-death mean since being a confirmed case as calculated in Table III. Once again, we assume that the case does not feel symptoms before being confirmed by medical tests. Time-until-death in September is around or less than one, suggesting we must detect COVID-19 as fast as possible to prevent deaths. The need is urged for the population under 30 in a country where many RT-PCR facilities provide testing results in one day or more. Early antigen testing detection could help decrease diagnostic delays and onward viral transmission [35]. The condition gets even better if antigen tests are done in high frequency [36]. M stands for male, and F stands for female.

TABLE III
MEAN OF TIME-UNTIL-DEATH DISTRIBUTION (IN DAYS)

Age Group	July 2020		August 2020		September 2020	
	M	F	M	F	M	F
0 – 9	0.08	0.08	0.03	0.02	0.03	0.03
10 – 19	0.07	0.08	0.10	0.10	0.28	0.30
20 – 29	0.53	0.56	0.57	0.59	0.85	0.86
30 – 39	2.13	2.22	1.36	1.39	1.11	1.11
40 – 49	4.31	4.41	1.78	1.79	1.17	1.17
50 – 59	5.69	5.78	1.91	1.92	1.18	1.18
60 – 69	6.26	6.35	1.87	1.87	1.14	1.14
70 – 79	5.21	5.32	1.63	1.63	1.10	1.10
80 – 89	5.56	5.70	1.70	1.80	1.12	1.11
90 – 99	5.56	5.64	1.87	1.87	1.17	1.17

Relating results from Table I and Table III, assuming that there are no newer COVID-19 variants, we may have this disease easily healed in the long run even without any treatments, as the mean lifespan converges to one. However, as the mean of time until death is also decreasing, this disease could also be a silent killer.

IV. Conclusion

We modeled time-until-death due to COVID-19 and time until being released from the hospital since an individual is confirmed as a case. We used the double-decrement model by assuming that time-until-release follows the Weibull hazard form and time-until-death follows the log-logistic hazard form. Males and females have similar characteristics of both time-until-death and time-until-release when cases with symptoms have less mortality risk than cases without any symptoms. Full dose vaccination, serious effort to keep body fitness, and more frequent rapid antigen testing could minimize the risk of getting and transmitting this disease; when RT-PCR testing facilities upgrade is also important to obtain results faster.

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