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ANALYSIS OF COVID-19 FOMITE TRANSMISSION MODEL WITH DISINFECTANT SPRAY

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Abstract
The SARS-CoV-2 virus causes the infectious disease COVID-19. This virus can be transmitted via the fomite mode of transmission (the surface of objects contaminated with the virus). It is possible to prevent the spread of COVID-19 by spraying disinfectant on infected objects. This research aims to develop a mathematical model of COVID-19 fomite transmission with disinfectant spraying intervention. The model was analyzed by determining its stability and critical point. A Ro analysis was conducted to determine the impact of disinfectant spraying on the eradication or spread of the disease. The results demonstrated that, in the absence of disinfectant spraying, the number of infected humans increased rapidly and abruptly. Based on the findings of sensitivity analysis, it is known that spraying disinfectants is highly effective at reducing Ro, thereby reducing the number of infected humans and eradicating the disease from the population. In this study, the recommended measure to prevent the spread of COVID-19 is the periodic application of disinfectant in accordance with medical regulations.

Keywords: *COVID-19, Fomite Transmission, Mathematical Model, Disinfectant Spraying*

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1. INTRODUCTION

At the end of 2019, the world was shocked by the outbreak of COVID-19, which claimed numerous lives. COVID-19 is caused by the SARS-Cov-2 virus, whose initial appearance is believed to have originated in the Chinese city of Wuhan [1], [2], and [3]. This virus spreads rapidly among human populations. COVID-19 infects almost every nation on the planet. The first confirmed case of COVID-19 in Indonesia occurred on March 2, 2020 [2]. According to WHO data from July 26, 2020, COVID-19 has infected 15,785,641 people worldwide in approximately eight months. It was reported that 640,016 of the total number of infected had died [4]. The World Health Organization (WHO) identified COVID-19 as a global pandemic that could threaten human life on March 11, 2020, after conducting a scientific study.

The direct transmission of COVID-19 between humans has been extensively studied. Among them is a study by ITB mathematician Nuning Nuraini and colleagues using the Richard Curve Model to predict the peak of COVID-19 in Indonesia [5]. Hadi Susanto, a researcher and Professor of Applied Mathematics at Khalifa University, used the SI Model to estimate the rate of direct transmission of COVID-19 in Jakarta [6]. However, there are still few studies that discuss the epidemiological model of the spread of COVID-19 via intermediary surface objects, such as doorknobs, contaminated by infected humans and then touched by healthy humans (fomite mode of transmission).

The reality on the ground indicates that COVID-19 can spread indirectly through objects touched by an infected individual. The virus-contaminated objects are then touched by healthy humans. These items are doorknobs made of stainless steel and plastic, such as water bottles [7], [8], and [9]. WHO explains that COVID-19 can survive for five days on plastic surfaces such as plastic bottles, for 48 hours on stainless steel such as doorknobs, and for four days on glass materials such as glass [8], [9], and [10]. In addition, a study conducted in a Singapore hospital isolation room revealed that SARS-Cov-2 was detected on the doorknob of the restroom [8]. Considering that COVID-19 can spread through fomite transmission, it is essential to conduct research on the COVID-19 fomite transmission model.

Fomite transmission begins when infectious liquid droplets adhere to an object's surface, resulting in fomites (contaminated surfaces) that are then touched by healthy, susceptible humans and reach facial areas such as the mouth and nose. By spraying disinfectants, the spread of COVID-19 through the fomite mode of transmission can be prevented. Disinfectants are toxic chemical substances that can kill microorganisms like bacteria and viruses. Formaldehyde, chlorhexidine, cetrimide, ethylene oxide, halogen, chlorine, or hydrogen peroxide are typical components of disinfectants[11]. In daily life, disinfectant solutions are typically composed of floor or ceramic cleaning fluid and detergent diluted in water.

Coronavirus can be inactivated in one minute with 62–71 percent ethanol, 0.5 percent hydrogen peroxide, or 0.1 percent sodium hypochlorite [12]. According to Pottage et al. [13], hydrogen peroxide is an effective disinfectant for eliminating viruses. Hydrogen peroxide functions through the formation of H-O, which reacts with thiol groups in proteins, lipids, and nucleic acids. As a result, the virus' nucleic acids and proteins cannot replicate, and the virus perishes. According to the WHO's report, RT-PCR tests on objects that had been sprayed with disinfectants, such as doorknobs, tables, chairs, stethoscopes, floors, and windows, were negative, according to the WHO's report [10].

Mathematical modeling is essential to analyze the behavior of COVID-19's spread. Through model analysis, it is possible to comprehend the rate of COVID's spread and the best methods for managing and controlling the disease. Interventions based on the analysis of the disease's most influential parameters will yield effective and efficient results.

This study's primary objective is to develop a model for the spread of COVID-19 via the fomite mode of transmission with the intervention of disinfectant spraying. The human population is divided into three groups: *susceptible*, *infected*, and *recovered*. Objects made of fomite that can facilitate the transmission of the COVID are separated into two compartments: the *susceptible* object compartment and the *infected* object compartment. The resulting model is then examined for its equilibrium point, the stability of the equilibrium point, and the basic reproduction ratio (*Ro*). Through sensitivity analysis to *Ro*, the parameters with the greatest impact on the spread of COVID-19 were determined. Knowledge of parameters that have a significant impact on the spread of COVID-19 will influence the selection of appropriate, effective, and efficient control measures.

2. RESEARCH METHOD

This research employs a literature review to identify pertinent theories, followed by the development of an epidemiological model of the COVID-19 disease's spread. The literature review begins with a search for information on the nature and spread of the COVID-19 virus. In addition, searches of the scholarly literature were conducted to identify the SIR differential equation model. This study's primary model for describing the transmission of the COVID-19 virus is the SIR model. These are the phases and procedures of the conducted research:

1. A research study of the characteristics and mode of transmission of the SARS-Cov-2 (COVID-19),
2. Identify assumptions,
3. Constructing a transmission diagram for the COVID-19,
4. Constructing a mathematical model of COVID-19 transmission by using the disinfectant spraying,
5. Perform a stability analysis after determining the disease-free equilibrium point and the endemic equilibrium point,
6. Create the NGM matrix and assign R_o,
7. Numerical simulations and interpret simulation results, and
8. Conduct a sensitivity analysis to determine the parameters that influence the transmission of COVID-19.

3. RESULT AND DISCUSSION

3.1. COVID-19 Transmission Model

The human population in the transmission of COVID-19 can be divided into three groups/compartments based on field observations. These compartments are *susceptible* (S); *infected* (I), which is the human compartment infected with COVID-19; and *recovery* (R) humans, which is the human compartment that has recovered from COVID-19. In this study, the fomite transmission modeled is the doorknob. The doorknob is separated into two compartments: *susceptible* (G_s) and infected (G_i) doorknobs. G_s is a doorknob that does not contain the virus or droplets from infected humans but is susceptible to infection. G_i is a doorknob that contains droplets of the COVID-19 virus.

In this study, it is assumed that COVID-19 can be transmitted via the fomite mode, with the doorknob serving as an intermediary. Contact with the virus-infected doorknobs is capable of infecting healthy humans. On the other hand, it is assumed that the doorknob is contaminated because it was touched by an infected person who left behind virus droplets. Humans who have been recovered are assumed to have permanent immunity. Meanwhile, it is assumed that door handles have been disinfected by spraying disinfectant on doorknobs. The number of infected doorknobs can be reduced. The percentage of infected doorknobs sprayed with disinfectant was α. The infected doorknob will be reduced to $G_i(1 - \alpha)$ door handle as a result of spray. The following diagram illustrates the complete transmission.

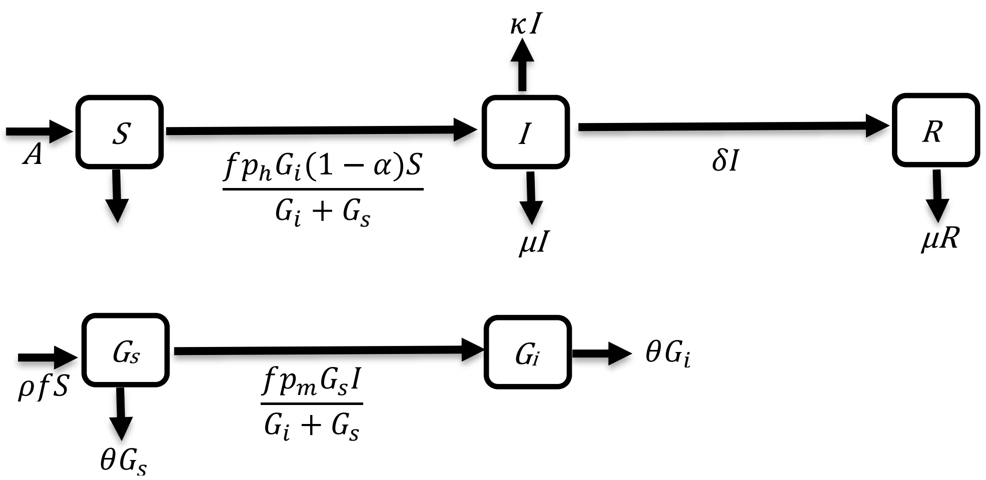

Figure 1. Diagram of COVID-19 Fomit Transmission Through Door Handles

The following is Table 1, containing the model's parameters.

Table 1. List of model parameters

Parameters	Information	Unit
A	Recruitment rate for human *susceptible*	Human/unit of time
f	The frequency of infected individuals touching door handles	Numerous contacts/unit of time
p_h	Successful probability of transmitting the virus from an infected doorknob to a healthy individual	-
N	The total human population	Man
α	The proportion of contaminated doorknobs treated with disinfectant spray	-
μ	Human natural date rate	1/unit of time
κ	The rate of human mortality caused by infected	1/unit of time
δ	The transition rate from infected humans to recovered humans	1/unit of time
ρ	Probability found new doorknobs from humans *susceptible*	-
p_m	Successful probability of transmitting the virus from an infected human to a susceptible doorknob	-
θ	Damage natural rate from doorknob	1/unit of time

Based on the transmission diagram in **Figure 1**, the mathematical model is constructed as follows:

$$\begin{aligned}
\frac{dS(t)}{dt} &= A - \frac{f p_h G_i(t)(1-\alpha)S(t)}{G_i(t)+G_s(t)} - \mu S(t) \\
\frac{dI(t)}{dt} &= \frac{f p_h G_i(t)(1-\alpha)S(t)}{G_i(t)+G_s(t)} - \kappa I(t) - \delta I(t) - \mu I(t) \\
\frac{dR(t)}{dt} &= \delta I(t) - \mu R(t) \\
\frac{dG_s(t)}{dt} &= \rho f S(t) - \frac{f p_m G_s(t) I(t)}{G_i(t)+G_s(t)} - \theta G_s(t) \\
\frac{dG_i(t)}{dt} &= \frac{f p_m G_s(t) I(t)}{G_i(t)+G_s(t)} - \theta G_i(t)
\end{aligned} \qquad (1)$$

of all positive parameter values, that expressed as $A > 0$, $f > 0$, $0 \leq p_h \leq 1$, $0 \leq \alpha \leq 1$, $\mu > 0$, $\kappa > 0$, $\delta > 0$, $0 \leq \rho \leq 1$, $0 \leq p_m \leq 1$ and $\theta > 0$. The average number of human births per year is $A = \mu N(t)$.

3.2. The Equilibrium Point of the COVID-19 Fomite Transmission Model

The disease-free equilibrium (DFE) and the endemic equilibrium (END) are two equilibrium points in the dynamic model of the COVID-19 fomite distribution in system (1). The DFE equilibrium point describes a state in which the human population is free of disease. At the DFE equilibrium point, the number of infected human compartments (I) and infected doorknobs (G_i) are equal to zero, thereby achieving an infection-free state. The equilibrium point of the DFE is:

$$DFE = \left\{ I = 0, R = 0, S = \frac{A}{\mu}, G_i = 0, G_s = \frac{Af\rho}{\mu\theta} \right\} \qquad (2)$$

if there are no infected individuals and doorknobs ($I = G_i = 0$), the existence of a disease-free equilibrium point is guaranteed. In the meantime, the human population in the healthy compartment and on doorknobs that were free of the virus is positive (S, $G_s > 0$).

In addition, the point of endemic equilibrium is reached when both the human compartment and the infected doorknob are positive. Endemic equilibrium point is defined as END = (S^*, I^*, R^*, G_s^*, G_i^*). The following is END of system (1):

$$\begin{aligned}
S^* &= \frac{p_m A}{(\alpha-1) f p_h p_m + (\delta+\kappa+\mu)\rho - \mu p_m} \\
I^* &= \frac{A((\alpha-1) f p_h p_m + (\delta+\kappa+\mu)\rho)}{(\delta+\kappa+\mu)((\alpha-1) f p_h p_m + (\delta+\kappa+\mu)\rho - \mu p_m)} \\
R^* &= \frac{\delta A((\alpha-1) f p_h p_m + (\delta+\kappa+\mu)\rho)}{(\delta+\kappa+\mu)((\alpha-1) f p_h p_m \mu + (\delta+\kappa+\mu)\rho\mu - \mu^2 p_m)}
\end{aligned} \qquad (3)$$

$$G_s{}^* = \frac{A\rho^2(\delta+\kappa+\mu)}{(\alpha-1)^2 f p_h{}^2 p_m\theta-(\alpha-1)\theta\mu p_h p_m+(\alpha-1)\rho\theta p_h(\delta+\kappa+\mu)}$$
$$G_i{}^* = \frac{A\rho^2(\delta+\kappa+\mu)+(\alpha-1)A\rho f p_h p_m}{(\alpha-1)^2 f p_h{}^2 p_m\theta-(\alpha-1)\mu p_m p_h\theta+\rho\theta p_h(\alpha-1)(\delta+\kappa+\mu)}$$

The existence of this endemic equilibrium point is guaranteed if all populations in each compartment are positive ($S > 0, I > 0, R > 0, G_s > 0$ dan $G_i > 0$).

3.3. Disease Free Equilibrium (DFE) Point Stability

The stability of the Disease Free Equilibrium point (DFE) is determined by evaluating the eigenvalues of the Jacobi matrix resulting from system (1) linearization, around the DFE equilibrium point. The Jacobi DFE matrix is

$$Jacobian\ DFE = \begin{bmatrix} -\mu & 0 & 0 & 0 & -\frac{p_h(1-\alpha)\theta}{\rho} \\ 0 & -\kappa-\delta-\mu & 0 & 0 & \frac{p_h(1-\alpha)\theta}{\rho} \\ 0 & \delta & -\mu & 0 & 0 \\ \rho f & -f p_m & 0 & -\theta & 0 \\ 0 & f p_m & 0 & 0 & -\theta \end{bmatrix}. \quad (4)$$

The Jacobian DFE (4) has five eigenvalues, with three eigenvalues negative, $\lambda_1 = -\mu$, $\lambda_2 = -\mu$, and $\lambda_3 = -\theta$. The next two eigenvalues are λ_4 and λ_5 determined by the equation's roots

$$\lambda^2\rho + (\delta\rho + \kappa\rho + \mu\rho + \theta\rho)\lambda + \alpha f\theta p_h p_m - f\theta p_h p_m + \delta\rho\theta + \kappa\rho\theta + \mu\rho\theta = 0. \quad (5)$$

Let, $a = \rho$, $b = \delta\rho + \kappa\rho + \mu\rho + \theta\rho$, and $c = \alpha f\theta p_h p_m - f\theta p_h p_m + \delta\rho\theta + \kappa\rho\theta + \mu\rho\theta$ be the quadratic equation coefficients for equation (5). Based on the Vieta Theorem, it is known that equation (5) will produce negative roots ($\lambda_4 < 0$ dan $\lambda_5 < 0$), when the value $c > 0$. Consequently, for the DFE equilibrium point to be stable, it must be:

$$\alpha f\theta p_h p_m - f\theta p_h p_m + \delta\rho\theta + \kappa\rho\theta + \mu\rho\theta > 0$$
$$f\theta p_h p_m(\alpha - 1) > -\rho\theta(\delta + \kappa + \mu)$$
$$\frac{f p_h p_m(1-\alpha)}{\rho(\delta+\kappa+\mu)} < 1$$

If $R_o{}^2 = \frac{f p_m p_h(1-\alpha)}{\rho(\delta+\kappa+\mu)}$ and $R_o{}^2 < 1$, then the disease free equilibrium point is asymptotically stable.

3.4. Endemic Equilibrium (END) Point Stability

The stability of the endemic equilibrium point is known based on the characteristic value of the Jacobi matrix resulting from system (1) linearization which is evaluated in the endemic equilibrium point. The eigenvalues obtained from the endemic Jacoby matrix consist of five eigenvalues with two negative eigenvalues, namely $\lambda_1 = -\mu$ and $\lambda_2 = -\theta$. The next three eigenvalues are λ_3, λ_4 and λ_5 determined by the equation's roots

$$a\lambda^3 + b\lambda^2 + c\lambda + d = 0 \quad (6)$$

where,

$a = (\delta + \kappa + \mu)\rho p_m$

$b = -(\delta + \kappa + \mu)^2\rho^2 + \big(-f p_m p_h\rho(\alpha - 1) + \rho(2\mu + \delta + \kappa)\big)(\delta + \kappa + \mu) - f\theta p_h p_m{}^2(\alpha - 1)$

$c = -(\delta + \kappa + \mu)^2(\mu + \delta + \kappa - \theta)\rho^2 - \big(-\mu^2 + (f p_h(\alpha - 1) - \delta - \kappa + \theta)\mu + f(\delta + \kappa - 2\theta)(\alpha - 1)p_h + \theta(\delta + \kappa)\big)p_m(\delta + \kappa + \mu)\rho + p_m^2(f(\alpha - 1)p_h - 2\mu - \delta - \kappa)(\alpha - 1)\theta f p_h$

$d = \big((f(\alpha - 1)p_h - \mu)p_m + \rho(\delta + \kappa + \mu)\big)\theta(\delta + \kappa + \mu)\big(f(\alpha - 1)p_h p_m + \rho(\delta + \kappa + \mu)\big).$

If the roots of equation (6) have negative ($\lambda_3 < 0, \lambda_4 < 0$ and $\lambda_5 < 0$), then endemic equilibrium point is asymptotically stable. According to the Vieta Theorem, because $a > 0$ then the equation (6) it will produce roots which are all negative if $b > 0$, $c > 0$ and $d > 0$. Thus, must

1. $-(\delta+\kappa+\mu)^2\rho^2 + \left(-fp_m p_h \rho(\alpha-1) + \rho(2\mu+\delta+\kappa)\right)(\delta+\kappa+\mu) - f\theta p_h {p_m}^2(\alpha-1) > 0$, which is fulfilled if ${R_o}^2 = \frac{fp_m p_h(1-\alpha)}{\rho(\delta+\kappa+\mu)} > 1$,
2. $-(\delta+\kappa+\mu)^2(\mu+\delta+\kappa-\theta)\rho^2 - \left(-\mu^2 + (fp_h(\alpha-1) - \delta - \kappa + \theta)\mu + f(\delta+\kappa-2\theta)(\alpha-1)p_h + \theta(\delta+\kappa)\right)p_m(\delta+\kappa+\mu)\rho + p_m^2(f(\alpha-1)p_h - 2\mu - \delta - \kappa)(\alpha-1)\theta f p_h > 0$, which is fulfilled if ${R_o}^2 = \frac{fp_m p_h(1-\alpha)}{\rho(\delta+\kappa+\mu)} > 1$, and
3. $\left((f(\alpha-1)p_h - \mu)p_m + \rho(\delta+\kappa+\mu)\right)\theta(\delta+\kappa+\mu)\left(f(\alpha-1)p_h p_m + \rho(\delta+\kappa+\mu)\right) > 0$, which is fulfilled if ${R_o}^2 = \frac{fp_m p_h(1-\alpha)}{\rho(\delta+\kappa+\mu)} > 1$.

thus, the endemic equilibrium point will be asymptotically stable if ${R_o}^2 > 1$.

3.5. Next Generation Matrix (NGM) and Basic Reproduction Number ($\boldsymbol{R_o}$)

The Basic Reproduction Number, denoted by R_o is a threshold value indicating whether an infectious disease is endemic (increased) or eradicated from a population. R_o has a threshold value of 1. The value of the basic reproduction number falls into one of the three categories below [14].

(i) $R_0 < 1$, individuals infected with the disease will automatically disappear from the population.
(ii) $R_0 = 1$, individuals infected with the disease will always exist in the population.
(iii) $R_0 > 1$, the number of infected individuals will increase and exist in the population.

Diekmann [15] describes how to obtain the basic reproduction number (R_o) is to create a matrix, *Next Generation Matrix* (NGM). The NGM form of the dynamic model of the transmission fomite of COVID-19 by disinfectant spraying on system (1) is

$$NGM = \begin{bmatrix} 0 & \frac{p_h(1-\alpha)}{\rho} \\ \frac{fp_m}{\delta+\kappa+\mu} & 0 \end{bmatrix} \tag{7}$$

with characteristic polynomial from NGM (7) is $P(\lambda) = \rho(\delta+\kappa+\mu)\lambda^2 + f(\alpha-1)p_h p_m$. Consequently, the greatest eigenvalue represents the basic reproduction number (R_o) is given by

$$R_o = \sqrt{\frac{f(1-\alpha)p_h p_m}{\rho(\delta+\kappa+\mu)}}$$

3.6. Numerical Results

The following values are assumed for the simulation's required parameters.

Table 2. List of parameter values

$\boldsymbol{A}$	$\boldsymbol{f}$	$\boldsymbol{\mu}$	$\boldsymbol{p_h}$	$\boldsymbol{\alpha}$	$\boldsymbol{\alpha}$	$\boldsymbol{p_m}$	$\boldsymbol{\kappa}$	$\boldsymbol{\delta}$	$\boldsymbol{\rho}$	$\boldsymbol{\theta}$
$\frac{20000}{65\times 365}$	5	$\frac{1}{65\times 365}$	0,1	$\frac{6}{10}$	$\frac{1}{10}$	$\frac{2}{10}$	$\frac{1}{100}$	$\frac{1}{60}$	$\frac{3}{10}$	$\frac{1}{1000}$

The initial values chosen for each compartment are shown in **Table 3**.

Table 3. The initial values

$\boldsymbol{S(0)}$	$\boldsymbol{I(0)}$	$\boldsymbol{R(0)}$	$\boldsymbol{G_s(0)}$	$\boldsymbol{G_i(0)}$
500	10	0	30	2

The following figure depicts the outcomes of a numerical simulation of changes in the human population using the parameter values and initial conditions from **Tables 2** and **3**.

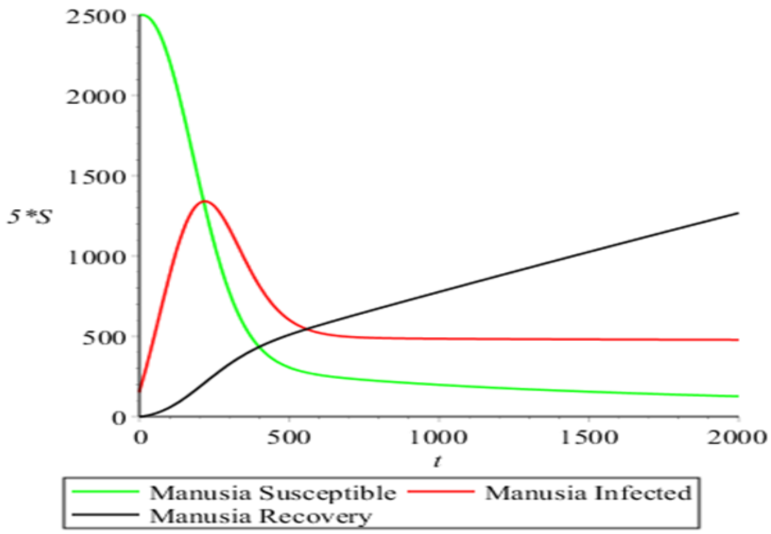

Figure 2. Population changes graphics in each compartment for α = 0,6

The following diagram depicts the simulation results of comparing the infected human population for the values of α = 0,1 and α = 0,6.

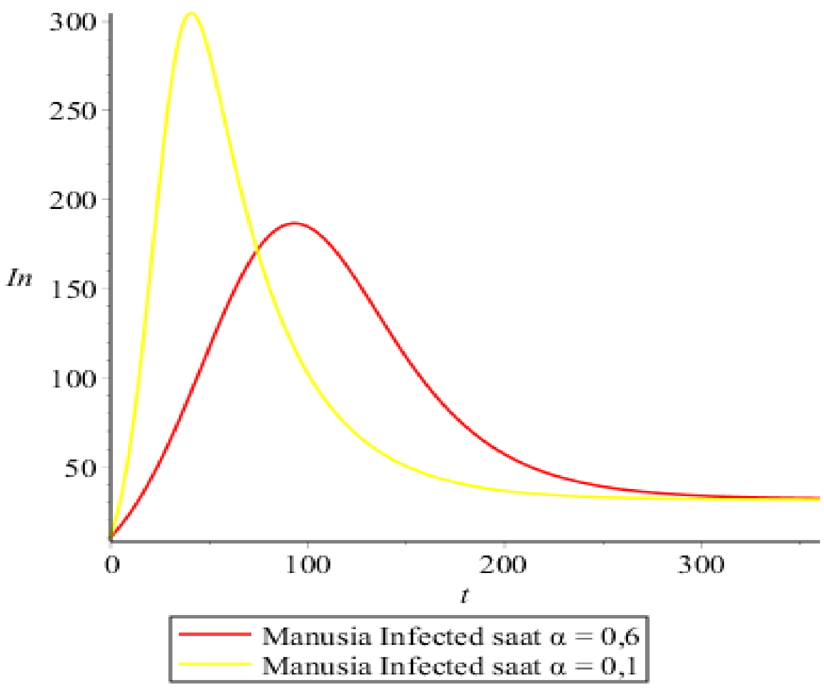

Figure 3. Graph comparing infected human populations at different values of α

Figure 2 is the result of a numerical simulation for the dynamics of population in each compartment with a proportion of disinfectant spraying equal to 0,6 (α = 0,6). Infection with the COVID-19 virus decreases the number of susceptible humans, which then stabilizes after some time. The number of infected humans initially increases until it reaches a peak, after which it decreases until it reaches a point of stability. This disease is present in the human population and will not disappear. Human recovered population increases as more infected individuals recover. This population dynamic occurs when $R_o = 2{,}23 > 1$, an endemic value for COVID-19 in the population.

Figure 3 this demonstrates the effect of spraying disinfectant on doorknobs on the number of infected individuals. As shown by the yellow curve, when the proportion of disinfectant spraying is low i.e., only $\alpha = 0{,}1$, the number of infected humans increases rapidly. In contrast, when the proportion of disinfectant spraying is increased by $\alpha = 0{,}6$, the growth of infected humans becomes low. This is represented by the red line. This simulation's interpretation that a large proportion of disinfectant sprays can control or reduce the number of infected humans and the population's infection rate.

3.7. Sensitivity Analysis

The objective of sensitivity analysis is to identify the most influential parameters in a model of disease spread. Through this analysis, the effect of modifying a parameter on *Ro* will be clearly discernible. The **Figure 4** displays the results of the sensitivity analysis of the COVID-19 fomite transmission model by spraying disinfectant.

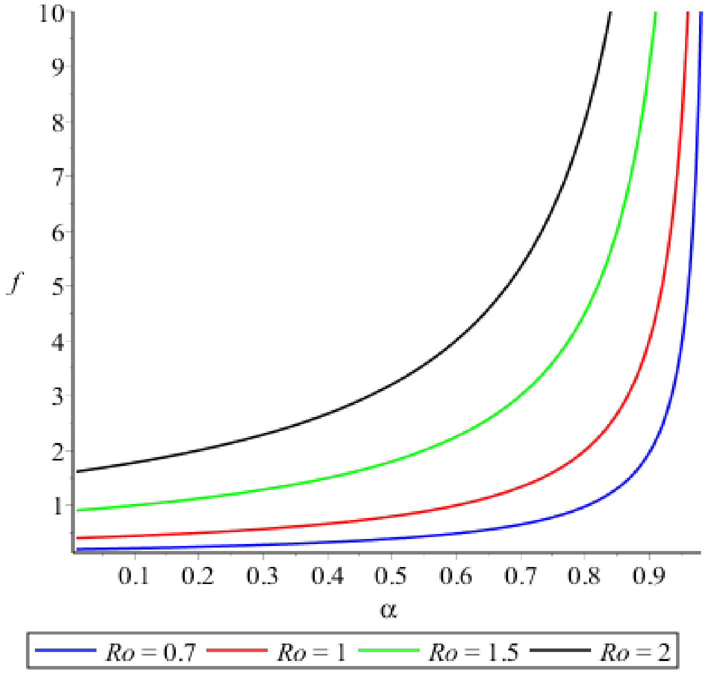

Figure 4. Sensitivity Analysis of the COVID-19 Fomite Transmission Model

Based on the results of the sensitivity analysis depicted in **Figure 4**, it can be seen that the parameters of the frequency of contact/touching the doorknob (f) and the proportion of disinfectant spraying (α) have a significant impact to R_o. **Figure 4** shows that the value of R_o increases with increasing value of parameter f and decreasing value of α. On the other hand, R_o will be decreasing as the value of f is decreased and the value of α is increased. This means that the greater the frequency of contact (f) between infected humans and doorknobs and the less frequently disinfectants are sprayed, the higher the number of infected humans and the more endemic the disease will be in the population.

4. CONCLUSION

Based on the results, it can be concluded the following:

1. The spread of COVID-19 is possible through fomite transmission and can be mathematically modeled.
2. The equilibrium points of model are disease free equilibrium point (DFE) = $\left\{I = 0, R = 0, S = \frac{A}{\mu}, G_i = 0, G_s = \frac{Af\rho}{\mu\theta}\right\}$ and endemic equilibrium (END) point = $(S^*, I^*, R^*, G_s^*, G_i^*)$.
3. The basic reproduction number (R_o) is

$$R_o = \sqrt{\frac{f p_h p_m (1-\alpha)}{\rho(\delta + \kappa + \mu)}}$$

4. The results demonstrated that spraying disinfectants significantly reduced the transmission of the COVID -19 by fomite transmission inadequate spraying of disinfectants on objects with the potential to become fomite transmission media results in a relatively rapid increase in the number of infected humans. In contrast, spraying disinfectants will reduce or inhibit the spread of the virus, thereby reducing the number of infected humans.

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