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Alternative Strategies to Eradicate Corruption in Indonesia with Numerical Simulation of 4th Order Runge Kutta Method on Mathematical Models

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Abstract. Corruption remains a critical issue hindering Indonesia's development across various sectors, necessitating innovative approaches to combat it. This study explores alternative strategies to eradicate corruption by leveraging mathematical modelling and numerical simulations. A dynamic system representing corruption propagation is formulated, considering key variables such as enforcement intensity, public awareness, and policy effectiveness. The 4th-order Runge Kutta method simulates the model and analyzes the impact of various strategic interventions over time. The results show that the difference in initial conditions significantly affects the level of corruption, which increases or decreases in a specific time. These findings provide valuable insights for policymakers and stakeholders in designing effective, data-driven anti-corruption strategies, emphasizing the integration of rigorous mathematical tools with socio-political frameworks. The study highlights the potential of numerical simulations as a complementary approach to traditional qualitative analyses in addressing complex societal challenges like corruption.

Keywords: Corruption, Mathematics Model, 4th order Runge Kutta method

1 Introduction

Indonesia, as a country rich in natural resources and has excellent development potential, is still faced with serious challenges in the form of corruption. Corruption threatens sustainable development, economic equality, and the strengthening of state institutions [1]. The importance of combating corruption is not only related to moral and ethical aspects but also directly because corruption has affected economic development, investment, and social stability. Transparency International's Survey Institute and Index show that Indonesia still has significant levels of corruption compared to other countries with similar GDP per capita. This has a huge impact on various sectors, including public services, state financial management, and investment [2].

One of the serious impacts of corruption is the decline in public trust in government and public institutions [3]. This can hamper people's participation in development and increase the level of social inequality. Therefore, the need for serious efforts to eradicate corruption is not only to fulfill legal demands, but also as a strategic step to build a clean, transparent and accountable state. Along with the increasing awareness of the negative impact of corruption, a number of researchers have offered various strategies and approaches to eradicate corruption in Indonesia. The strategies and approaches offered in the research cover legal, social, economic, political and religious aspects [4], [5], [6], [7]. Various dimensions, ranging from improving regulations to strengthening law enforcement agencies and empowering communities have also been offered. However, although various strategies and approaches have been taken in order to eradicate corruption in Indonesia, empirical reality shows that the level of corruption in the country still remains high and even tends to increase [8]. This phenomenon, on the one hand, shows that all the offers that have been made to eradicate corruption in Indonesia have not been fully appropriate or effective in their implementation. Therefore, a more comprehensive alternative approach is needed to eradicate corruption in Indonesia.

This research offers an alternative strategy to eradicate corruption in Indonesia using a mathematical model approach. A mathematical model is one of the concentrations in mathematics that tries to approach and translate a phenomenon in life (in this case, corruption behavior in Indonesia) into mathematical equations that describe the phenomenon [9]. The mathematical modeling in this study will consider the main factors in eradicating corruption, namely active community participation, improving regulations, and strengthening law enforcement agencies.

This research discusses numerical simulation of corruption dynamics in Indonesia using the 4th order Runge Kutta method. The main purpose of numerical simulation is to solve complex mathematical problems using computational methods. Some differential equations, algebraic or integral equations may not easily obtain analytical solutions directly. Numerical solutions using iterative or discretization methods are present to calculate solutions that are close to the actual solution. The Runge Kutta method is one of the methods used to find numerical solutions of both linear and non-linear ordinary differential equations with a higher degree of accuracy than the Euler method but still efficient in calculation. Through this research, it is expected to be shown how the 4th order Runge Kutta method works in obtaining numerical solutions of a system of nonlinear differential equations modeling the dynamics of corruption in Indonesia with certain initial conditions.

2 Research Method

This research method is conducted using a mathematical model approach to understand the dynamics of the spread of corruption in Indonesia and evaluate its eradication strategy. The developed model groups the population into five categories: Vulnerable Group (S), Immune Group (I), Corrupt Group (C), Prisoner Group (J), and Reformist Group (R) [10]. This approach is carried out by compiling a system of differential equations to describe the interactions between groups and analyze the factors that affect the transition of individuals from one group to another.

The data used in this study are taken from the literature and previous case studies that observe the phenomenon of corruption in Indonesia. Factors such as the level of corruption contacts, the success of individuals in switching between groups, and the level of law enforcement are modeled into mathematical equations. To facilitate analysis, this system is simplified into a fraction system, where each variable represents the population proportion in each group at any given time [11]. The mathematical model obtained is a system of nonlinear ordinary differential equations. In the system of differential equations, there are five ordinary differential equations that describe the dynamics of the Vulnerable Group (S), Immune Group (I), Corrupt Group (C), Prisoner Group (J), and Reformist Group (R). Because the analytical solution of the differential equation system is not easy to obtain, the runge kutta order 4 method is used in this study to determine the solution computationally or numerically.

3 Mathematics Model

In this article, the total population (N) is further grouped into five compartments namely: Vulnerable Group (S), Immune Group (I), Corrupt Group (C), Prisoner Group (J), and Reformist Group (R). Vulnerable Group (S) is a group consisting of individuals who have never been involved in corrupt practices, but are vulnerable to corrupt practices in society. The vulnerable group results from the birth of individuals with good moral standards. Individuals who are vulnerable to corruption have two possibilities: they can move into the corrupt group or into the immune group. They will move to the corrupt group if they are successfully influenced due to their interaction with corrupt individuals. Conversely, they will enter the immune group if they cannot be influenced due to their interaction with corrupt individuals. Likewise, if they have high faith so that they can take lessons from every corruption event, which will strengthen themselves not to commit corruption. Meanwhile, the immune group (I) is a group consisting of individuals who have moral standards and will never be involved in corrupt practices, no matter what happens to the circumstances around them.

The Corruptor Group (C) is a group consisting of individuals who are often involved in corrupt practices and are able to influence vulnerable parties to become perpetrators of corruption. Corrupt individuals after getting the right orientation through public enlightenment leave the corrupt group towards the reformist group. Corrupt individuals who are prosecuted and imprisoned leave the corrupt group towards the imprisoned group.

The Prisoner Group (J) is a class of individuals who are imprisoned for a certain period of time for corruption. While in prison this group cannot engage in acts of corruption and cannot influence others to commit corruption. Incarcerated individuals will become reformist individuals after getting the right orientation through public enlightenment. Meanwhile, the Reformist (R) group is a group consisting of ex-convicts who have been reformed while serving their prison terms, but are still vulnerable to corruption. On the other hand, the Reformist group (R) is still possible to interact with the immune group (I). If so, it is expected that the Reformist group (R) will be immune forever.

The mathematical model of the dynamics of corruption behavior above can be depicted in a compartment diagram as shown in Figure 1 below.

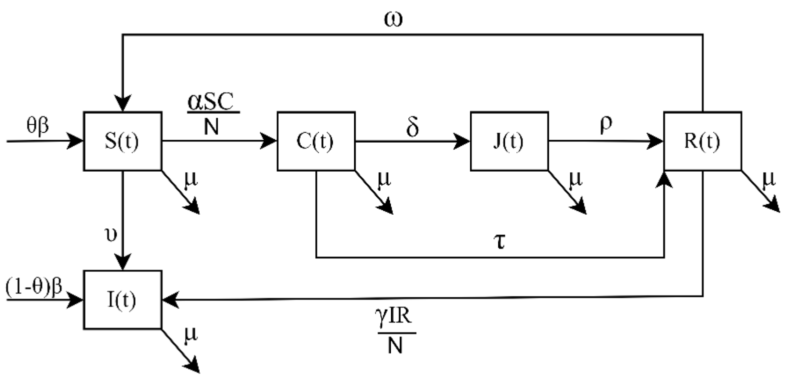

Fig 1. Schematic diagram of the dynamic model of corruption transmission.

The parameters involved in the above compartment diagram are defined in Table 1 below.

Table 1. Parameter Definition

No	Parameter	Description
1	θ	The proportion of individuals who do not have immunity, which is the ability of a person to defend himself from corruption.
2	β	Birth rate of individuals entering the population
3	α	Effectiveness of vulnerable individuals interactions with corrupt individuals
4	γ	Effectiveness of reformed individuals interaction with immune individuals
5	ω	Success rate of reformist individuals turning into corruption-prone individuals
6	υ	The degree to which vulnerable individuals become immune to corruption
7	δ	Prosecution and imprisonment rates for corrupt actors
8	τ	Success rate of corrupt individuals becoming reformers due to public enlightenment
9	ρ	Success rate of incarcerated individuals becoming reformed individuals

10	μ	Natural mortality rate

Furthermore, the compartment diagram in Figure 1 can be expressed in a mathematical model expressed as the initial value problem of the following nonlinear system.

$$S'(t) = \theta\beta - \frac{\alpha S(t)C(t)}{N} - (\mu + v)S(t) + \omega R(t) \tag{1}$$

$$I'(t) = (1 - \theta)\beta + vS(t) - \mu I(t) + \gamma I(t)R(t) \tag{2}$$

$$C'(t) = \alpha S(t)C(t) - (\mu + \tau + \delta)C(t) \tag{3}$$

$$J'(t) = \delta C(t) - (\mu + \rho)J(t) \tag{4}$$

$$R'(t) = \tau C(t) + \rho J(t) - \frac{\gamma I(t)R(t)}{N} - (\mu + \omega)R(t) \tag{5}$$

The variable $[S(t), I(t), C(t), J(t), R(t)]$ represents the percentage of individuals in the population at a given time who belong to vulnerable, immune, corruptor, convict, or reformist groups. Differential equations (1) to (5) are a system of nonlinear differential equations that describe the mathematical model of corruption dynamics in Indonesia.

4 Results and Discussion

4.1 Runge Kutta 4th Order Method

The 4th order Runge Kutta method is one of the numerical methods to find the solution of differential equations. This method is one of the most popular because of its high accuracy and ease of use. The following describes the Runge kutta 4th order method for finding numerical solutions to differential equations [14], [15].

Given differential equation $\frac{dy}{dx} = f(x, y)$ have solution:

$$y_{i+1} = y_i + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)\Delta x$$

with

$$k_1 = f(x_i, y_i)$$

$$k_2 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}\Delta x k_1)$$

$$k_3 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}\Delta x k_2)$$

$$k_4 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}\Delta x k_3)$$

4.2 Runge Kutta 4th order method for modeling corruption in Indonesia

If written $y = (S, I, C, J, R)^T$ and $f = (f_1, f_2, f_3, f_4, f_5)^T$ then the 4th order Runge Kutta method for the system of differential equations that consists of five differential equations to describe the dynamics of the vulnerable group (S), the immune group (I), the corrupt group (C), the convict group (J), and the reformist group (R).

The 4th order Runge Kutta method for the differential equation of Vulnerable Group (S) dynamics is

$$S_{i+1} = S_i + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4)\Delta x$$

where

$k_1 = f_1(t_i, S_i, I_i, C_i, J_i, R_i)$

$k_2 = f_1\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_1, I_i + \frac{1}{2}\Delta x l_1, C_i + \frac{1}{2}\Delta x m_1, J_i + \frac{1}{2}\Delta x n_1, R_i + \frac{1}{2}\Delta x p_1\right)$

$k_3 = f_1\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_2, I_i + \frac{1}{2}\Delta x l_2, C_i + \frac{1}{2}\Delta x m_2, J_i + \frac{1}{2}\Delta x n_2, R_i + \frac{1}{2}\Delta x p_2\right)$

$k_4 = f_1\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_3, I_i + \frac{1}{2}\Delta x l_3, C_i + \frac{1}{2}\Delta x m_3, J_i + \frac{1}{2}\Delta x n_3, R_i + \frac{1}{2}\Delta x p_3\right)$

The 4th order Runge Kutta method for the differential equation of immune group dynamics (I) is

$$I_{i+1} = I_i + \frac{1}{6}(l_1 + 2l_2 + 2l_3 + l_4)\Delta x$$

where

$l_1 = f_2(t_i, S_i, I_i, C_i, J_i, R_i)$

$l_2 = f_2\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_1, I_i + \frac{1}{2}\Delta x l_1, C_i + \frac{1}{2}\Delta x m_1, J_i + \frac{1}{2}\Delta x n_1, R_i + \frac{1}{2}\Delta x p_1\right)$

$l_3 = f_2\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_2, I_i + \frac{1}{2}\Delta x l_2, C_i + \frac{1}{2}\Delta x m_2, J_i + \frac{1}{2}\Delta x n_2, R_i + \frac{1}{2}\Delta x p_2\right)$

$l_4 = f_2\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_3, I_i + \frac{1}{2}\Delta x l_3, C_i + \frac{1}{2}\Delta x m_3, J_i + \frac{1}{2}\Delta x n_3, R_i + \frac{1}{2}\Delta x p_3\right)$

The 4th order Runge Kutta method for the differential equation of Corrupt Group dynamics (C) is

$$C_{i+1} = C_i + \frac{1}{6}(m_1 + 2m_2 + 2m_3 + m_4)\Delta x$$

where

$m_1 = f_3(t_i, S_i, I_i, C_i, J_i, R_i)$

$m_2 = f_3\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_1, I_i + \frac{1}{2}\Delta x l_1, C_i + \frac{1}{2}\Delta x m_1, J_i + \frac{1}{2}\Delta x n_1, R_i + \frac{1}{2}\Delta x p_1\right)$

$m_3 = f_3\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_2, I_i + \frac{1}{2}\Delta x l_2, C_i + \frac{1}{2}\Delta x m_2, J_i + \frac{1}{2}\Delta x n_2, R_i + \frac{1}{2}\Delta x p_2\right)$

$m_4 = f_3\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_3, I_i + \frac{1}{2}\Delta x l_3, C_i + \frac{1}{2}\Delta x m_3, J_i + \frac{1}{2}\Delta x n_3, R_i + \frac{1}{2}\Delta x p_3\right)$

The 4th order Runge Kutta method for the differential equation of Group dynamics of Prisoners (J) is

$$J_{i+1} = J_i + \frac{1}{6}(n_1 + 2n_2 + 2n_3 + n_4)\Delta x$$

where

$n_1 = f_4(t_i, S_i, I_i, C_i, J_i, R_i)$

$n_2 = f_4\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_1, I_i + \frac{1}{2}\Delta x l_1, C_i + \frac{1}{2}\Delta x m_1, J_i + \frac{1}{2}\Delta x n_1, R_i + \frac{1}{2}\Delta x p_1\right)$

$n_3 = f_4\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_2, I_i + \frac{1}{2}\Delta x l_2, C_i + \frac{1}{2}\Delta x m_2, J_i + \frac{1}{2}\Delta x n_2, R_i + \frac{1}{2}\Delta x p_2\right)$

$n_4 = f_4\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_3, I_i + \frac{1}{2}\Delta x l_3, C_i + \frac{1}{2}\Delta x m_3, J_i + \frac{1}{2}\Delta x n_3, R_i + \frac{1}{2}\Delta x p_3\right)$

The 4th order Runge Kutta method for the differential equation of the dynamics of the Reformist Group (R) is

$$R_{i+1} = R_i + \frac{1}{6}(p_1 + 2p_2 + 2p_3 + p_4)\Delta x$$

where

$p_1 = f_5(t_i, S_i, I_i, C_i, J_i, R_i)$

$p_2 = f_5\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_1, I_i + \frac{1}{2}\Delta x l_1, C_i + \frac{1}{2}\Delta x m_1, J_i + \frac{1}{2}\Delta x n_1, R_i + \frac{1}{2}\Delta x p_1\right)$

$p_3 = f_5\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_2, I_i + \frac{1}{2}\Delta x l_2, C_i + \frac{1}{2}\Delta x m_2, J_i + \frac{1}{2}\Delta x n_2, R_i + \frac{1}{2}\Delta x p_2\right)$

$p_4 = f_5\left(t_i + \frac{1}{2}\Delta x, S_i + \frac{1}{2}\Delta x k_3, I_i + \frac{1}{2}\Delta x l_3, C_i + \frac{1}{2}\Delta x m_3, J_i + \frac{1}{2}\Delta x n_3, R_i + \frac{1}{2}\Delta x p_3\right)$

4.3 4th order Runge Kutta Method Simulation with Python

This simulation is conducted to model the dynamics of the spread of corruption cases using the SICJR model with the 4th order Runge Kutta method where the variables

1. $S(t)$: Individuals vulnerable to corruption
2. $I(t)$: Individuals who are immune to corruption
3. $C(t)$: Individuals who have committed corruption
4. $J(t)$: Individual prisoners
5. $R(t)$: Individuals recovering or released from prison

The 4th order Runge Kutta method is used to calculate new values every time step $\Delta t = 0.1$ based on a non-linear differential equation. With this, we can model the dynamics between groups.

The simulation above shows the results of modeling corruption cases using the 4th order Runge-Kutta method with three different initial conditions:

1. Simulation 1:

- Initial conditions: $S_0 = 100$, $I_0 = 1$, $C_0 = 0$, $J_0 = 0$, $R_0 = 0$.

- At first, the value of S (uninvolved group) dominates, but decreases over time due to interaction with the I (affected) group. The values of $I, C, J,$ and R increase with their respective dynamics.

2. Simulation 2:

- Initial conditions: $S_0 = 80$, $I_0 = 5$, $C_0 = 10$, $J_0 = 0$, $R_0 = 0$.

- With the condition that C_0 is already larger at the beginning, the contribution of the corruption group is more visible, and the dynamics of the spread of corruption shows a faster pattern.

3. Simulation 3:

- Initial conditions: $S_0 = 50$, $I_0 = 20$, $C_0 = 5$, $J_0 = 5$, $R_0 = 0$).

- In this condition, a high initial value for I accelerates the spread of corruption to the C, J and R groups, while S decreases dramatically faster.

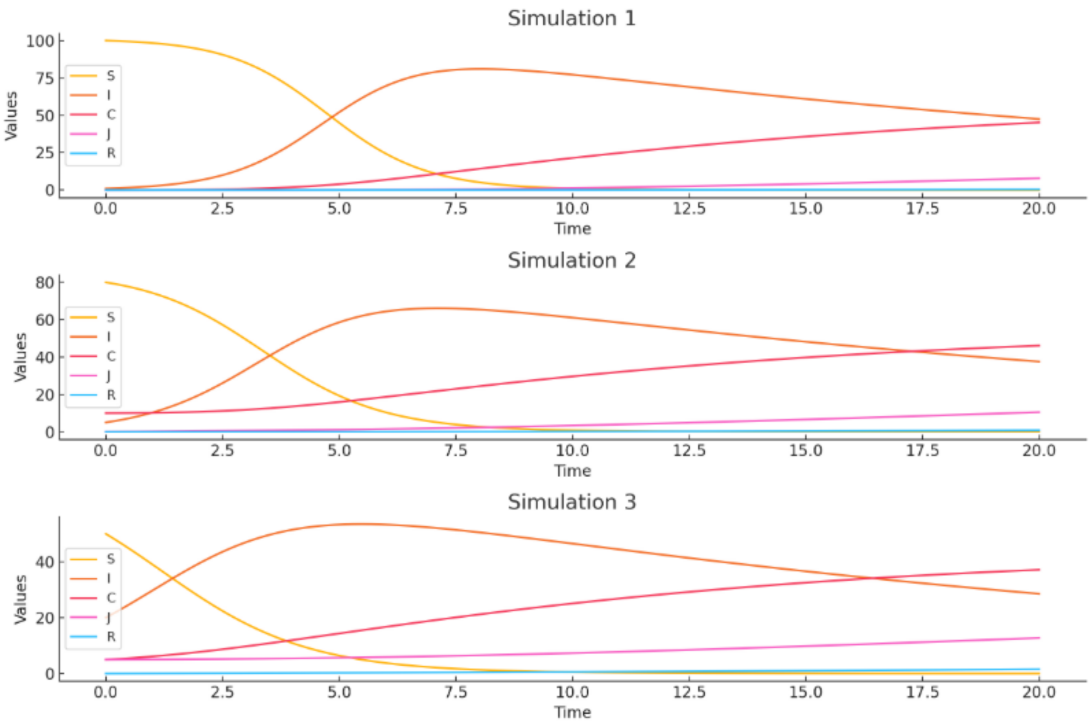

Fig 2. Model Simulation using Runge Kutta 4th Order

The simulation results show how the dynamics of the spread of corruption differ based on the initial conditions of the system. In the first simulation, when the majority of the population is in the S group (not yet involved in corruption) and only a few in the I group (starting to be affected), the spread of corruption occurs more slowly. The I group slowly grows, which then triggers an increase in C (actively involved), followed by the J (exposed), and R (out of the system) groups. This pattern suggests that with controlled initial conditions, the spread of corruption takes longer to develop.

In contrast, in the second and third simulations, when the initial value of I or C is larger, the spread of corruption becomes much faster. Under these conditions, the S (uninvolved) group decreases dramatically from the start, due to direct interaction with the already affected (I) or actively involved (C) group. The third simulation shows the most intense pattern, where the large number of affected individuals from the beginning causes the S group to be almost depleted in a short time, and the R group to increase faster due to the process of leaving the system. This result highlights the importance of keeping the population in S as much as possible at the beginning to slow down the spread of corruption.

5 Conclusion

The outcomes of the simulation demonstrate how the dynamics of corruption spread vary according to the system's beginning conditions. Corruption spreads more slowly in the first simulation when most people are in the S group (not yet involved in corruption) and just a small percentage are in the I group (beginning to be impacted). The C (actively involved), J (exposed), and R (out of the system) groups rise in response to the I group's gradual growth. This pattern implies that corruption spreads more slowly under regulated initial conditions. However, in the second and third simulations, the corruption spreads more when the initial value of I or C is higher. This result highlights the importance of keeping the population in S as much as possible at the beginning to slow down the spread of corruption.

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