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Dynamic Decision-Making Model Analysis for Pandemic Spread Control Using Causal Loop Diagram

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ABSTRACT

Global pandemics such as COVID-19 have highlighted the importance of swift and effective decision-making in controlling disease transmission. This study aims to analyze the dynamics of decision-making in pandemic control through a system dynamics approach using a causal loop diagram (CLD). By identifying key elements and feedback relationships among the main variables, the model illustrates the complex interactions within a disease spread system. The analysis reveals that government intervention, public compliance, and healthcare system capacity significantly influence the rate of transmission. This model is expected to serve as a reference for developing more adaptive policies in response to future health crises.

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1. INTRODUCTION

The current development of ICT (Information and Communication Technology) drives the provision of information across all fields, especially in decision-making systems, to enhance, develop, and update every piece of information available in order to support quality service delivery [1][2]. IT resources refer to any technology that helps individuals create, modify, store, transmit, and/or distribute information [3], [4]. Information technology combines high-speed processing and communication for the transmission of data, voice, and video [5]. Since late 2019 until early 2020, the health sector was shaken by the emergence of a mysterious virus in China, which rapidly spread across the globe. It was later identified that MERS, or a similar virus, was capable of causing severe illness [6], [7]. On February 11, 2020, the World Health Organization (WHO) assigned a specific name to the disease caused by the novel coronavirus: COVID-19, short for "coronavirus disease 2019." Subsequently, the novel coronavirus was named SARS-CoV-2, which stands for Severe Acute Respiratory Syndrome Coronavirus 2 [8], [9].

The COVID-19 outbreak that emerged in late 2019 has significantly affected various sectors, including health, economy, and society [10]–[12]. The rapid spread of the virus has required well-structured and timely policy responses from multiple stakeholders. In such a complex and uncertain environment, effective decision-making becomes a crucial factor in reducing the transmission rate of the disease [13].

Dynamic decision-making models offer a relevant approach to tackling this challenge. Using system dynamics, the interconnections between influencing variables can be mapped visually and systematically [14]. One of the tools used in this method is the causal loop diagram (CLD), which depicts feedback loops within a complex system. This diagram facilitates understanding of the interactions among factors that drive disease spread and assists in designing policies that are more responsive and adaptable to changing conditions.

By interpreting the system's dynamics through CLDs, policymakers can identify leverage points—specific areas of intervention that can generate significant impacts on the entire system [15]

Therefore, this study aims to construct and analyze a dynamic decision-making model in the context of pandemic spread control to offer strategic insights for future health policy planning [15].

The application of system dynamics in epidemiological studies has grown significantly, particularly for understanding disease transmission patterns and the impact of policy interventions. System dynamics allows researchers to map interrelated causal structures and model feedback mechanisms in complex systems [14].

Causal Loop Diagrams (CLDs) serve as essential tools in system dynamics, helping to visualize interactions among system elements. CLDs identify reinforcing and balancing loops, which are crucial for analyzing mechanisms that drive either the escalation or control of disease spread [15].

In the context of a pandemic, several studies have employed CLDs to illustrate how social policies—such as quarantine, mobility restrictions, and public health campaigns—affect infection rates [16], [17]. Furthermore, public engagement and risk communication have been recognized as significant factors influencing the effectiveness of disease control strategies.

2. METHODOLOGY

2.1. System Approach with Causal Loop Diagram (CLD)

This research adopts a system dynamics approach to model decision-making processes in the context of pandemic spread control. This method is chosen for its capability to represent causal relationships and complex interactions among variables within a dynamically changing system [14].

The first step involves identifying key variables that contribute to disease transmission, such as infection rate, healthcare capacity, public compliance, and government intervention policies. These variables are derived from literature reviews and analysis of empirical data and policy reports related to the COVID-19 pandemic [10], [18].

The next stage involves constructing a causal loop diagram (CLD) that visualizes the interactions among these variables. The CLD is developed by considering the direction of relationships (positive or negative) and the type of feedback (reinforcing or balancing loops) to reflect the system's dynamic behavior [15].

The analysis is conducted qualitatively to understand the relationship patterns and to identify potential leverage points for more effective intervention in pandemic control strategies.

The CLD approach offers many benefits, including [19], [20]:

- Encouraging individuals to view systems from a broader perspective, both in terms of scale and time, to avoid narrow viewpoints.
- Providing a clearer and more justifiable description of causal chains.
- Facilitating effective communication and enhancing collaboration.
- Assisting in exploring alternative strategies and solutions to anticipate outcomes.
- Enabling better-informed decision-making positions.

Several factors need to be considered when constructing a CLD, including:

- Understanding the boundaries or scope of the problem.
- Starting with key or compelling variables.
- Asking how these variables affect and influence one another.
- Identifying the components involved.
- Using nouns to represent variables.
- Clearly indicating "S" (same) and "O" (opposite) signs during diagram creation.
- Designing circuits to be realistic and easy to understand so that appropriate modifications can be made to the diagram when necessary.

2.2. System Approach Model

A model is an abstraction of the real world that has been simplified to include only the essential parameters and variables presented in its structure. A model can represent an object, process, situation, system, or an abstraction thereof. In general, models are used to identify and explain the relationships among various components, actions and reactions, and cause-and-effect relationships [21]. The model used is expected to be adaptable to emerging problems, thus facilitating better understanding and problem-solving.

Models used in problem-solving can be represented in the form of diagrams, illustrations, or matrix tables. Commonly used forms include:

- **Venn Diagram** – useful for understanding the placement of subsystems within a supersystem.
- **Tree Diagram** – helpful for identifying factors related to the problem or system being studied.
- **Black Box Model** – also known as the input/output model, it refers to system transformation processes where the internal workings and actions are unknown or intentionally disregarded.

- **Organizational Element Model** – considers input, process, and output elements. Inputs include raw materials or resources; the process refers to subsystems within the organization that convert inputs into outputs; and the outputs represent the results of transforming input data, initially still in raw form. The final output is the end result of the process, and there is an element of outcome, which refers to the effect the system receives from its outputs, or the response/reaction of users or the environment toward the system.
- The **causal graph** is a model that emphasizes the dynamic complexity of a system. This model illustrates cause-and-effect relationships among the studied variables through solid curved lines—where one represents the causal variable and the other the effect variable.

3. RESULTS AND DISCUSSION

4.1. Analysis of Factors that Accelerate and Inhibit the Spread of the Coronavirus

The global COVID-19 pandemic, which has affected countries around the world including Indonesia, has had significant impacts on various sectors—ranging from economic and social environments to influencing natural conditions. Within just a few months, the rapid spread of the coronavirus drastically changed the way of life and the state of society in Indonesia. The virus, which first emerged in Wuhan, China, has globally claimed hundreds of thousands of lives and caused millions to fall ill.

Scientists across the globe have been racing to research vaccines and other methods to help control the spread of the coronavirus. The role of ICT is now critically important in supporting efforts to manage the spread of the virus. In this study, a model is developed to illustrate the dynamics of cause and effect between the various factors involved—both those that contribute to the acceleration of the virus's spread and those that serve to inhibit it.

These relationships are illustrated in the causal loop diagram shown below:

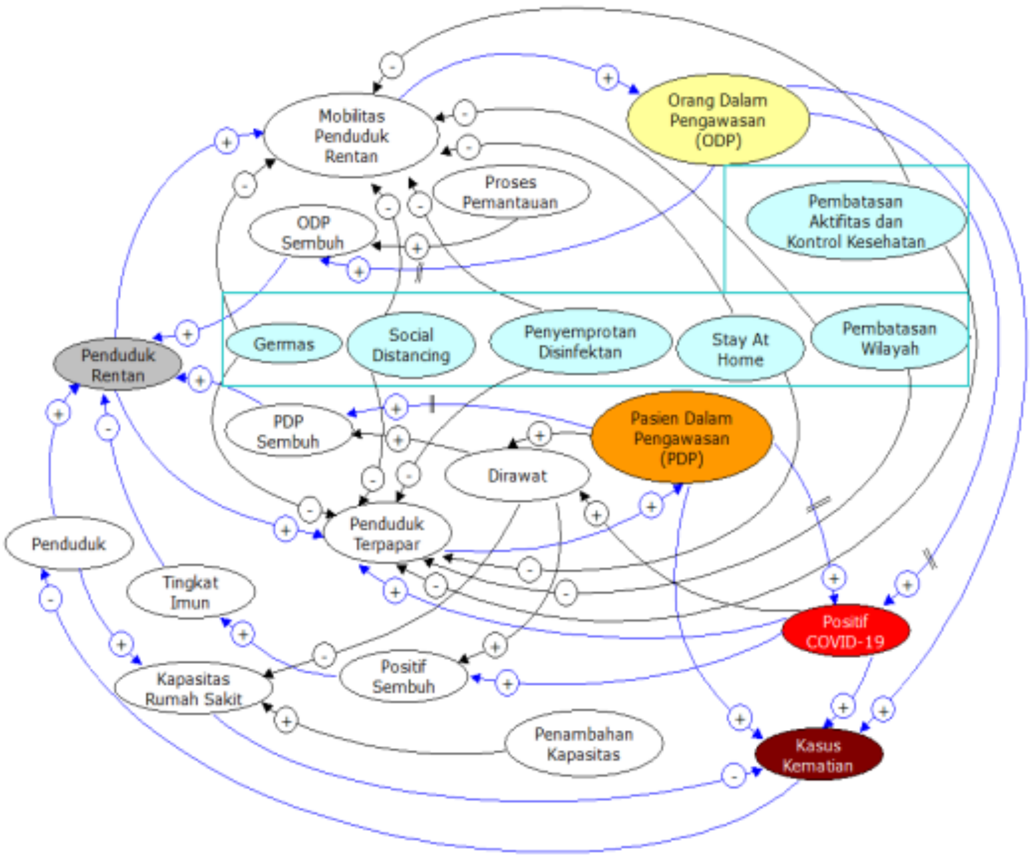

Figure 1 : Causal Loop Diagram Covid-19

Naturally, in order to contain the spread of the pandemic, it is important to identify several factors that influence the further transmission of the virus among confirmed positive cases. One of the most significant impacts of the virus has been on the economy—at national, regional, and individual levels. Schools and universities were closed (transitioning to online learning), offices were required to implement work-from-home (WFH) policies, travel during holiday seasons was restricted, markets and shopping centers were shut down, flights were grounded, ports were closed, and nearly all activities were limited.

The analysis of the causal loop diagram (CLD) reveals complex interactions among variables that influence the spread of a pandemic. Several key loops were identified:

- A reinforcing loop between the increasing number of cases and the burden on healthcare capacity. As cases rise, healthcare facilities become overwhelmed, potentially reducing service quality and worsening patient outcomes.
- A balancing loop involving social restriction policies and public compliance. Improved adherence to health protocols contributes to reduced infection rates, which helps stabilize the system.
- The government intervention loop illustrates how measures such as lockdowns or vaccination programs influence key variables, including population mobility and healthcare system responsiveness.

The CLD also highlights that delays in decision-making can exacerbate the situation due to the time lag between actions and observable outcomes. This underscores the importance of managing feedback delays in dynamic systems [14].

These findings support previous studies showing that rapid, data-driven, and socially supported decisions are crucial in suppressing disease transmission. Moreover, identifying leverage points, such as raising public awareness or expanding hospital capacity, can be effective both in the short and long term.

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4. Conclusion

Penelitian ini menunjukkan bahwa pendekatan sistem dinamis melalui penggunaan causal loop diagram (CLD) efektif untuk memetakan kompleksitas hubungan antar faktor dalam penyebaran pandemi. Temuan ini menekankan pentingnya intervensi yang cepat dan terkoordinasi, kepatuhan masyarakat terhadap protokol kesehatan, serta kesiapan kapasitas layanan kesehatan sebagai elemen kunci dalam mengendalikan laju penyebaran penyakit

In describing the model of virus transmission and response, the researchers employed a causal loop diagram (CLD) approach, with the aim of assisting the government and other stakeholders in understanding the complexities of decision-making relationships. This CLD model is used to identify the root causes of complex problems and the systemic impacts of virus mitigation efforts. The model serves as a foundational basis for developing simulation models that can be used to design and test alternative control policies.

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