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Accessibility of COVID-19 Vaccines in African Countries: A System Dynamics Model Examining Income, Logistics, and Governance

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Abstract

To combat the COVID-19 pandemic, pharmaceutical companies, biotech companies, national governments, and universities have jointly developed a variety of vaccines. After this stage, widespread and effective vaccination on a global scale has become the most crucial aspect in the fight against the pandemic. The discovery of vaccines has brought up the issue of how to deliver them quickly and fairly to those living in underdeveloped countries. Vaccination encompasses not only the medical aspect but also the concepts of accessibility, availability, equitable, fair, and rapid distribution as a whole. The main theme of our study is to comparatively highlight the impact of factors other than the medical aspect of vaccination on vaccination, specifically within the context of the African continent. African countries particularly have faced the most problems in accessing and distributing vaccines. This study aims to identify the barriers to the delivery of the Covid-19 vaccine to African countries. In this study, we analyzed the vaccine supply, governance index, and logistics infrastructure factors affecting access to vaccines in the context of various scenarios, using the system dynamics method. The findings of this study show that income level is the most significant variable. Additionally, improving logistics performance and infrastructure and governance index increase more equitable access to vaccines in African countries.

Keywords: Covid-19, Vaccine, Africa, System Dynamics, Logistics Infrastructure, Governance Index.

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1. INTRODUCTION

Vaccination stands as one of the most crucial tools in the battle against the COVID-19 virus. Some biotechnology companies, national governments, and universities have jointly developed various vaccines against the ongoing COVID-19 pandemic since December 2019. After the confirmation of the safety of the COVID-19 vaccine through research findings, two primary challenges were encountered. Firstly, there was the issue of gaining public acceptance of the vaccine and addressing potential concerns. In order to address the first challenge, studies utilizing a behavioral approach were published (Saleska and Choi, 2021). Subsequent to the approval of COVID-19 vaccines, vaccine logistics emerged as a universal problem. Global demand existed in the face of limited supply (Yamey et al., 2020). The limited vaccine supply brings about new challenges both between countries and within a country (Roope et al., 2020). It has been demonstrated that making swift political decisions is beneficial for the fair and egalitarian distribution of the COVID-19 vaccine, which proves to be a significant obstacle against the epidemic (Bollyky TJ et al., 2020). Governments without a clear plan may be compelled to make rapid decisions favoring groups with strong political connections instead of creating open, consistent, evidence-based guidelines for the fair and egalitarian distribution of the COVID-19 vaccine. Those at "personal risk" are prioritized in vaccine distribution, for example, frontline healthcare personnel. Additionally, among individuals at risk, such as bus drivers, they may be included in the priority group (Bonaccorsi et al., 2020).

After the vaccine development studies were completed, discussions began on how to deliver the vaccine to people quickly and fairly. While 65.4% of the world's population received at least one dose of the COVID-19 vaccine, only 15.7% of people in low-income countries received at least one dose (Ourworldindata, 2022). The World Health Assembly announced that 10% of each country's population vaccinated by the end of September 2021. Additionally, they aimed that 40% of each country's population will vaccinate by end of 2021. Although almost 90% of high-income countries achieved the goal, many African countries still did not reach the target. By the end of December 2021, 7 African countries with relatively smaller populations (Seychelles, Mauritius, Morocco, Tunisia, Comoros, Botswana, and Cape Verde) had met the 40% target. According to the new target set by WHO, 70% of the population of all countries is targeted to be vaccinated by June 2022, but this target may not be reached in African countries (BBC, 2021; Idris et al., 2022; Lucero-Prisno et al., 2021; WHO, 2022a). In September 2021, the World Health Organization (WHO) set an ambitious global target. The UN health agency has called for 70 percent of the global population to be vaccinated by mid-2022. At this point, just over 3% of people in low-income countries have been vaccinated with at least one dose, compared to 60.18% in high-income countries. Six months later, the world hasn't even come close to achieving that goal. The total number of vaccines administered has increased dramatically, but so has the inequality in distribution: of the more than 10 billion doses given worldwide, only one percent are administered in low-income countries.

Although vaccination is a medical intervention, without effective logistical planning, a successful vaccination campaign is impossible (Duijzer et al, 2018). Evelot Duijzer and colleagues, in their study, focus on the following three priorities of the World Health Organization as an operations research for a successful vaccination campaign related to Operations Research/Operations Management (OR/OM); 1-Products and packaging, 2-Immunization supply system efficiency, 3-Environmental impact of immunization supply system. In this context, vaccine packaging and products should be designed with suitable specifications, taking into account the needs and constraints of countries. The efficiency and agility of the vaccine supply system should be maximized by integrating it with other supply systems. This way, leveraging the synergy of other systems and supporting continuous improvement should be aimed at minimizing environmental side effects.

The developed vaccines were first distributed to healthcare workers in hospitals and then to people in the high-risk group. However, vaccination of all citizens will take a long time. It should not be forgotten that many factors such as technical, political, and ethical are taken into account, especially in making such national and international decisions regarding health. In addition, it is possible to say that other parameters such as uncertainties, safety, and effectiveness are effective both in the short term and in the long term in the logistics planning of the developed vaccine. However, the success of a global vaccine campaign depends on the rapid production and fair distribution of pandemic-specific vaccines worldwide. The logistical requirements for the delivery of the vaccine are outlined below (Supply Chain 247, 2021):

The most important factor in vaccine distribution is cold chain capacity. For example, the Pfizer vaccine needs to be stored below -70°C. However, the logistics system is not ready to fulfill this condition. In addition, there is a lack of infrastructure suitable for both hot climate and cold storage in some parts of South America, Asia, and Africa. This brings along the problem of a cold supply chain. For example, vaccines will likely become unusable if cooling is not available due to a power outage. Vaccine storage volumes are insufficient in parts of South America, Asia, and Africa, with a total population of more than six billion people. One of the biggest challenges in vaccine logistics is expressed as the "last mile delivery" concept. Specially trained personnel are required for the distribution and delivery of vaccines to the final delivery address after they reach the destination country. Therefore, access to rural health centers is extremely difficult.

COVID-19 cases and vaccine figures for the African continent as of May 2022 are (WHO, 2022b; Worldometer, 2022): According to the latest United Nations estimates, the population of Africa is 1,402,414,173, the total number of deaths from COVID-19 is 170,709. The total number of COVID-19 cases is 8.390.054. Eleven percent of adults living in Africa are vaccinated.

If the necessary interventions and aid are not started for the continent regarding vaccines, Africa's disease burden will last longer than expected (Lucero-Prisno et al., 2021). It is possible to indicate the reasons for the lack of vaccine supply and the effective distribution of vaccines inefficiently, especially in sub-Saharan African countries, as follows (Brookings, 2021; Economist, 2020; Idris et al., 2022; Lucero-Prisno, Ogunkola, Esu, et al., 2021; Lucero-Prisno, Ogunkola, Imo, et al., 2021; Mataba and Ismail, 2021; Ogunkola et al., 2020). Powerty has multiple and complex causes (Addae-Korankye, 2014). According to some politicians, it is poor because the former colonial powers want to keep it that way, not because of the choices made by African leaders. Others state that the cause of poverty is corruption or mismanagement. Besides that, Africa's infrastructure paradox and the lack of adequate financial resources for health infrastructure are among the causes of poverty. The private healthcare system is not developed, as financially advantaged people living in Africa prefer to travel abroad for health-related matters. 80 percent of infrastructure projects fail during feasibility and business planning. Foreign trade protective measures applied in many African countries, high customs taxes increase the cost of medical products and equipment. In addition, non-tariff barriers such as import procedures and customs procedures delay the delivery of critical medical supplies and equipment Finally, border conflicts, civil wars, violence, corruption, lack of good governance, democracy, and an insufficiently trained workforce and practices related to patent rights are among the hidden factors that hinder vaccine access in Africa.

Research Question: To what extent and in what direction do income level, logistics performance, and governance index affect people's vaccine accessibility in global pandemics?

Numerous interconnected factors are crucial in effective and widespread response to global disasters. We believe that income level, logistics infrastructure, and governance index play highly significant roles in the battle against COVID-19, which forms the central theme of our study. Especially considering the income levels and vaccination statuses of African countries, it is anticipated that the income level of countries will have a more significant positive impact on vaccine supply compared to other factors. Income level is expected to be effective in vaccine accessibility through its role in vaccine distribution, whereas the level of development of logistics infrastructure is expected to influence vaccine access. It is also believed that a high governance index will be highly effective in ensuring fair and equitable vaccine distribution, which is crucial in disaster response in general.

This article focuses on vaccine supply, governance index, and logistics infrastructure affecting vaccine access in African countries. This study evaluates vaccine access, population vaccinated in 24 months, vaccine demand, and loss of life in Africa in the light of scenarios. By simulating the system dynamics model, the impact of vaccine supply, governance index, and logistics infrastructure on vaccine access in African countries will be estimated.

2. LITERATURE REVIEW

Numerous studies have been conducted on the effective implementation and widespread distribution of vaccination across society. Our study's main focus is on vaccination, and it categorizes and elaborates on research concerning the impact of national income, governance index, and logistic performance and infrastructure on vaccination. The literature review section is organized into three main sections as follows:

2.1. The Relationship Between Vaccination and Income Level

One of the most significant factors affecting global vaccination is income level. An increase in national income will lead to higher healthcare expenditures. Consequently, an increase in the budget allocated to healthcare will have a positive impact on vaccination. Globally, it is observed that individuals living in high-income countries have easier access to vaccines compared to those in other countries. It has been observed that higher income is associated with better healthcare and better vaccination.

There are numerous studies that examine and investigate the impact of national income levels on vaccine accessibility. For instance, Masiva et al. (2018) adapted the standard conditional convergence model to incorporate variations in vaccination rates over time and across countries. They employed this modified model to project the macroeconomic gains derived from enhanced vaccination rates. Their findings revealed that increased investments in vaccination triggered by income growth yielded concrete economic benefits, which were linked to ongoing improvements. Basak et al. (2022), aiming to investigate the relationship between the GDP of various countries and vaccination rates, sought to explore how the model they developed operates at the continental level and examine the spatial distribution of progress in COVID-19 vaccination for all countries. They identified a strong linear relationship between per capita income and the proportion of vaccinated individuals in countries with a population of one million or more. Per capita GDP is responsible for a 50% variation in vaccination rates across countries. Furthermore, the global model was found to be applicable on every continent. It was observed that Rich Europe and North America were the most protected against COVID-19, while less developed African countries struggled with limited vaccination coverage. In a study conducted using the least squares method with data from 118 countries (Ngo et al., 2022), it was initially noted that authoritarian countries were slow in the vaccination process. However, their economic size facilitated vaccine supplies and directed them toward higher vaccination rates.

In a study examining vaccine hesitancy in China, conducted by Wang et al. (2021), a semi-structured face-to-face interview technique was employed with 92 Chinese individuals in 10 provinces following a predefined survey framework. It was suggested that trust, price, and recommendations influenced vaccination decisions. Additionally, it was observed that regions with higher per capita GDP had a higher belief in the benefits of vaccination.

MPhil et al. (2015), in their study examining the impact of vaccination on economic development, have argued that economic growth emerges only through the contribution of healthy individuals to the economy. Vaccination is considered a crucial factor in maintaining a healthy and productive labor force. It extends individuals' working lives, thus increasing their productivity over a longer period. Therefore, it has the potential to directly influence economic growth.

2.2. The Relationship Between Vaccination, Logistic Performance, and Infrastructure

At the onset of the COVID-19 pandemic, many governments were initially unsure about how to proceed. They encountered numerous challenges, from the procurement of protective equipment to issues of equitable, fair, and rapid distribution. The logistical and infrastructure problems in the distribution of essential pandemic-fighting products were evident, and it was clear that similar challenges would arise in the vaccination process where the target population is the entire populace. Additionally, countries with strong logistics performance and infrastructure were better equipped to overcome these challenges early on.

It is expected that countries with strong logistics performance and infrastructure will demonstrate a highly successful performance in achieving widespread vaccination. In their study examining the factors to consider when preparing a successful COVID-19 vaccination program in African countries, Williams et al. (2021) focus on lessons drawn from solutions proposed for the challenges encountered in previous vaccination efforts. These considerations range from improving weak infrastructure for data management and identifying adverse events post-vaccination to addressing logistical challenges in vaccination campaigns and assessing financing options to generate demand for vaccine supply. In conclusion, the COVID-19 pandemic, despite causing disruptions in global life and destabilizing economies, has also provided global leaders with an opportunity to reassess the fundamental healthcare infrastructure, preparedness, and response capacity for health emergencies in their respective countries.

Examining the correct delivery of COVID-19 vaccines to the entire global population, Shretta et al. (2021) in their articles, highlight that the existing vaccine supply chains are meticulously coordinated arrangements involving numerous stakeholders and components. They have stated that to ensure global coverage for an estimated 15 billion doses, it would require up to 200,000 pallet shipments and 15 million deliveries across various supply chains, in addition to 15,000 cargo aircraft flights. Developing a specific supply chain for COVID-19 vaccines could potentially have adverse effects on other supply chains.

2.3. The Relationship Between Vaccination and Governance Index

Democratic countries, under the condition of controlling other factors, tend to carry out vaccinations more rapidly compared to authoritarian countries. While democratic countries also grapple with vaccine hesitancy within their own borders, they have been observed to be more successful in vaccinating large segments of their populations compared to authoritarian nations (Ngo et al. 2022). However, there are studies that argue the opposite. Takshi Aida and Masahiro Shoji have proposed that there is no data to support the impact of the national governance index on the delivery of vaccines to citizens in developing countries. They have created a model to examine the relationship between the national governance index and vaccination in developing countries. This model, encompassing all countries, was compared with a model comprising non-OECD countries. As a result, contrary to their claims, it was found that the relationship between the governance index and vaccination is stronger in the non-OECD sample (Shoji and Aida, 2021). Baghbanzadeh et al. (2022) conducted a global analysis with the aim of examining the relationship between COVID-19 country-level morbidity and mortality data, vaccination, and the national-level governance index. They attempted to predict the morbidity and mortality of COVID-19 based on national governance index indicators (corruption index, transparency and accountability, political stability, and absence of violence and terrorism) and officially reported COVID-19 national data (cases and deaths per capita, and testing), as well as vaccination coverage. As a result, a strong relationship was observed between the national governance index and COVID-19 data. Countries were divided into three categories: politically stable countries, average countries, and less stable countries. According to the multivariate regression, politically stable countries reported more cases, more deaths, more testing, and more vaccination data compared to the other country groups. Politically less stable countries reported less data in all categories compared to countries in the other group.

Benati and Coccia (2022) conducted a global analysis by applying Independent Samples T-Test to examine the relationship between COVID-19 vaccinations and public governance. Analyzing over 110 countries worldwide, they provided evidence of a relationship between high and low levels of vaccination and indicators of public governance. The findings suggest that high-level governance can support the better functioning of the healthcare system.

3. MATERIALS AND METHODOLOGY

3.1. Model and Data Set

We analyze vaccine access in African countries with a system dynamics modeling approach. The system dynamics modeling helps to understand the behavior of complex systems over time. It observes the movement of complex problems in time by using the mathematical modeling method. Mathematical models are the core of system dynamics. This method was developed by Jay W. Forrester at MIT in the 1950s for understanding the behavior of industrial systems. This method represents the behavior of the system with various symbols within the framework of certain principles (Forrester, 1961). It contributes to understanding the complex relations not only in engineering but also in the social sciences, education, and communication to understand complex relationships.

The system dynamics method includes the simulation approach, cause-effect relationships, feedback loops, stock and flow diagrams, equations, and continuous simulation. It depends on 'information feedback theory' (Saysel et al., 2002).

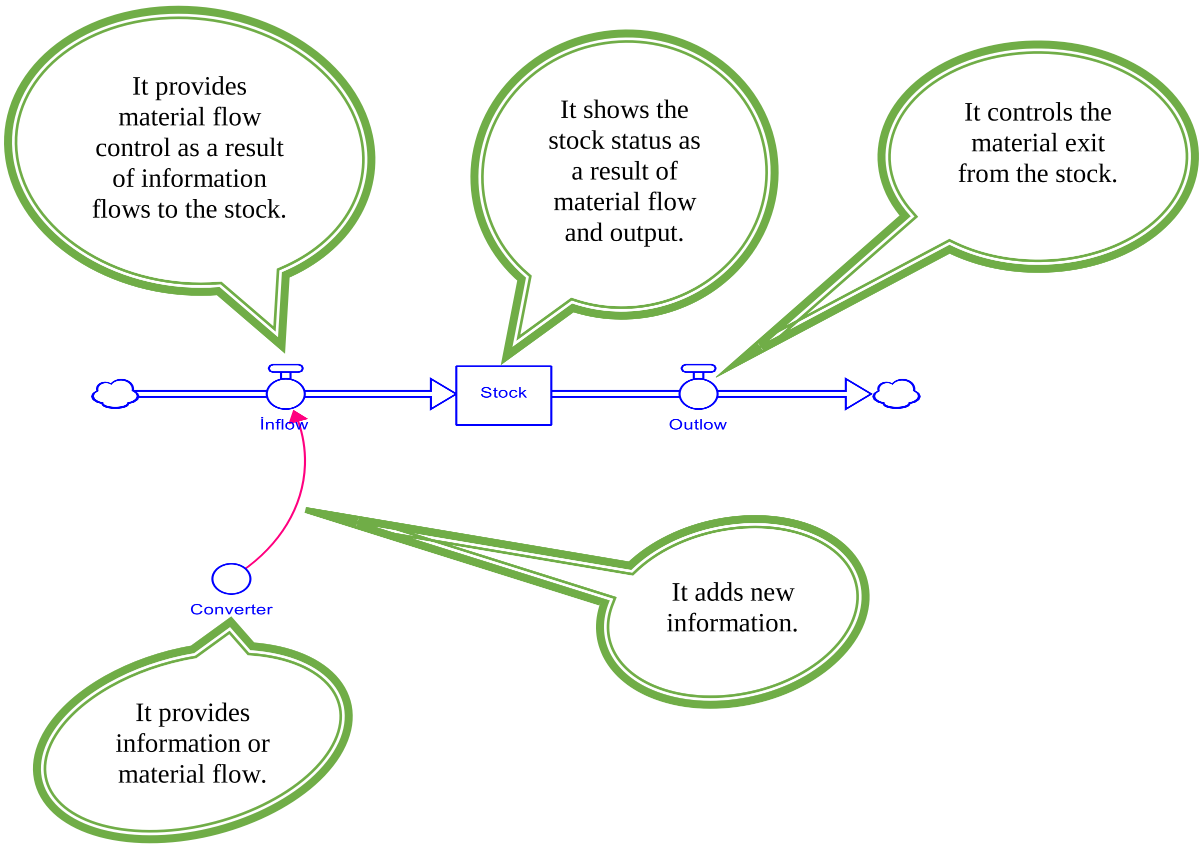
Cause and Effect Relationship: It provides understanding of cause-and-effect relationships between variables by modeling.

Feedback Loops: One-way causality between variables is insufficient to explain dynamic relationships. Circular causality with feedback is the main element that gives dynamism to the system.

Stock and Flow Diagrams: System dynamics modeling also illustrates the mutual and complex connections and feedback loops in the system by showing the accumulations in the system and the effects that cause these accumulations to decrease and increase over certain periods of time.

Equations and continuous simulation: In system dynamics, mathematical equations determine interrelated behavior measures of system variables. It provides a continuous simulation by repeating these behavior patterns at certain time intervals. Continuous simulation also helps to understand the movement of the system and to develop policy.

Figure 1. System Dynamics Modeling Approach Working Chart and Elements



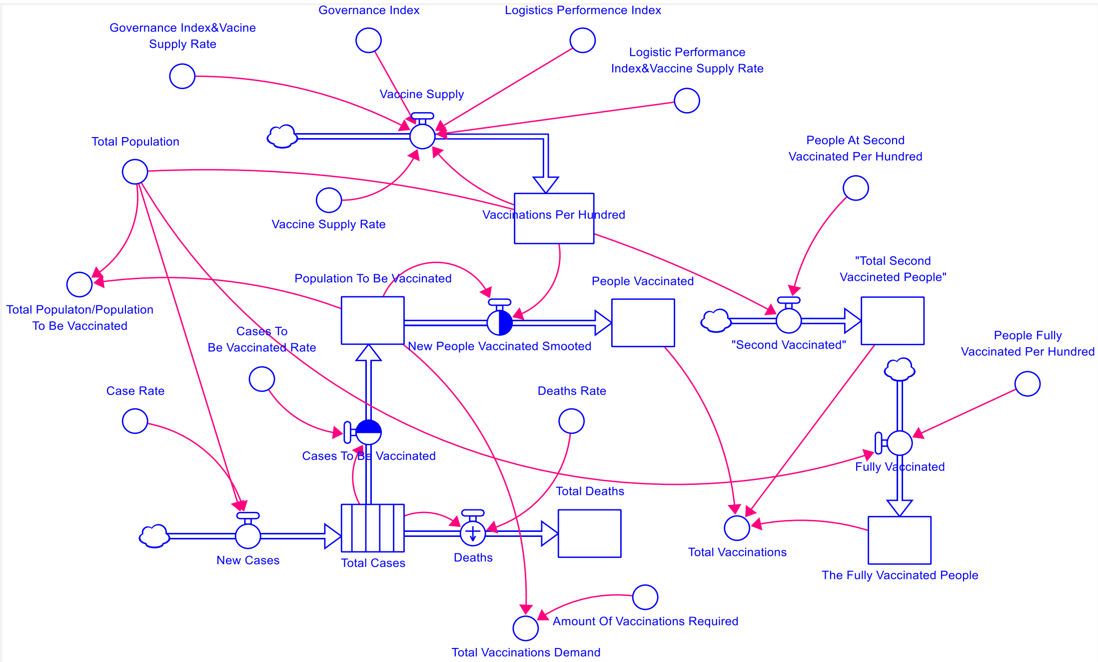
In Figure 1, a system with all its elements is modeled and simulated with the system dynamics approach. To understand the vaccine access problem in African countries, a simulation model was created with the system dynamics approach to propose solutions to the vaccine access problem in African countries by using the system dynamics approach. The data used in the model are taken from databank.org, World Bank, ourworldindata.org, freetradezone.africa.org and WHO data. In the light of the data obtained from these sources, the initial data for the stock variables and other necessary ratios were calculated and used in the model.

3.2. Methodology

In this study, the system dynamics simulation model, which was created to examine the effects of different variables on the access problem of COVID-19 vaccines in the African continent, was created with the help of the Stella computer-based package program. Stella consists of three main layers: the high-level map layer, the model building layer, and the equation building layer. First, the main system and subsystems were created in the top-level map layer. Then, feedback loops where stock and flow variables are placed are created in the model building layer. This layer is essentially the layer where the skeleton of the system is created and the direction of the relationship of the variables with each other is determined. Finally, with the help of mathematical equations, the degree, amount, and ratio of the relationship between the system variables were determined in the equation layer. Thanks to the equations created in this layer, the model gained vitality and dynamism.

In this study, the main system was created by considering the vaccination sub-model, population sub-model, governance index, vaccine supply and logistics performance sub-model and Covid-related loss of life sub-models in a holistic framework.

Figure 2. Availability Model of COVID-19 Vaccines in African Countries



The Figure 2 displays the model of the vaccine distribution system in African countries using the dynamic systems approach. As seen in the diagram, the population of Africa, logistical infrastructure, countries' income levels, and the governance index are depicted as stocks and flow variables to create the model illustrating the connection between vaccination and stock and flow variables in African countries. There are many factors that affect COVID-19 vaccine access, such as communication, culture, geographical structure, local and national dynamics, and beliefs. However, to determine the limits of the model we created, the model was created by taking the variables of governance index, logistics index and vaccine supply into the main axis, among the other factors affecting vaccine access. The governance index is an index that considers peace/security, democracy/laws, human rights/participation, sustainable development, and human development as a whole. The effect of this index on the vaccine; The average of the world governance index was calculated, then the average of vaccination in the world was calculated and the rate of vaccination per governance index was used in the model. Logistics performance index is calculated by calculating the world average from the World Bank data with the same method; The effect of average availability of vaccines on the average worldwide vaccine access was found and used in the model. Vaccine supply was also calculated using the same method.

Table 1 presents the calibration results of the model we created. The calibration of the model was performed using the optimization tool integrated into the package program we employed.

Table 1. Calibration Results

Method	recombine_type	f	crossover_type	tolerance	generations	pop_size	cr	k	seed
Differential Evolution	rand	0.6	bin	0.001	10	20	0.2	1	0

Payoff:	Payoff			
Action	minimize			
Element	Case Rate	Governance Index & Vacine Supply Rate	Logistic Performance Index & Vaccine Supply Rate	Vaccine Supply Rate
Weight	auto	auto	auto	auto
Comparison Variable	Case Rate	Governance Index & Vacine Supply Rate	Logistic Performance Index & Vaccine Supply Rate	Vaccine Supply Rate
Comparison Run	Run 1	Run 1	Run 1	Run 1
Comparison Type	Squared Error	Squared Error	Squared Error	Squared Error
Comparison Tolerance	0	0	0	0

Parameter:	Governance Index & Vacine Supply Rate	Logistic Performance Index & Vaccine Supply Rate	Case Rate	Vaccine Supply Rate
min_value	0	0	0	0
max_value	1	1	1	1

Payoff		
	min	max
Initialization	614.4399357	58200.02012
Generation 1 of 10	526.603966	44104.35083
Generation 2 of 10	526.603966	44104.35083
Generation 3 of 10	263.3132138	44104.35083
Generation 4 of 10	263.3132138	44104.35083
Generation 5 of 10	255.1793516	25243.30048
Generation 6 of 10	255.1793516	25234.09927
Generation 7 of 10	255.1793516	25216.66545
Generation 8 of 10	255.1793516	25204.54352
Generation 9 of 10	255.1793516	25204.54352
Generation 10 of 10	236.938059	4592.107466

	Governance Index & Vacine Supply Rate	Logistic Performance Index & Vaccine Supply Rate	Case Rate	Vaccine Supply Rate	Payoff
After 10 generations	0.900225786	0.000456622	0.03030966	0.030928398	236.9

As shown in Table 1, the calibration of the model was conducted by us using the differential evolution method.

The model, which was created on the axis of the problem of accessing COVID-19 vaccines in African countries, was calibrated through the optimization added to the Stella program, since calibration is a type of optimization. Then, the values calibrated in the model were used. Then, various scenario trials were conducted on the system dynamics simulation model, which was created and calibrated to find a solution to the problem of accessing COVID-19 vaccines in African countries.

3.3. Limitations of the Model

The model for the availability of COVID-19 vaccines in Africa has been developed by considering the continent as a whole. However, the national income, logistical infrastructure, and governance indices of the countries vary significantly. Therefore, the data used in the model and the results obtained do not reflect all African countries in a homogeneous manner.

Many variables influence COVID-19 vaccination, such as traditions, religion, healthcare infrastructure, cultural structure, geographical features, physical infrastructure, and human resources. However, our study examined the impact of only three variables on vaccination, thus ignoring the effects of other factors.

In African countries, lifestyle, cultural structure, geographical barriers, and governance gaps make it challenging to accurately record data on population, births, deaths, and vaccinations. Consequently, the continent-wide average data was used in the COVID-19 vaccine availability model for Africa.

3.4. Scenario Trials

In this study, which is based on examining the access to COVID-19 vaccines in African countries in the main axis of governance index, logistics performance and vaccine supply, scenario trials are also built on these three variables. Here, three different sub-scenario experiments for each variable will be made and in the light of the findings obtained, which variable will be examined to what extent and how it affects vaccine access.

To examine the factors influencing vaccine distribution in African countries, scenarios depicted in Table 2 have been created.

Table 2. Scenario Table

Scenarios	a-Status Qou	b-World	c-South Africa
Scenario-1 (Governance Index)	Scenario-1/a	Scenario-1/b	Scenario-1/c
Scenario-2 (Logistics Performance Index)	Scenario-2/a	Scenario-2/b	Scenario-2/c
Scenario-3 (Vaccine Supply)	Scenario-3/a	Scenario-3/b	Scenario-3/c

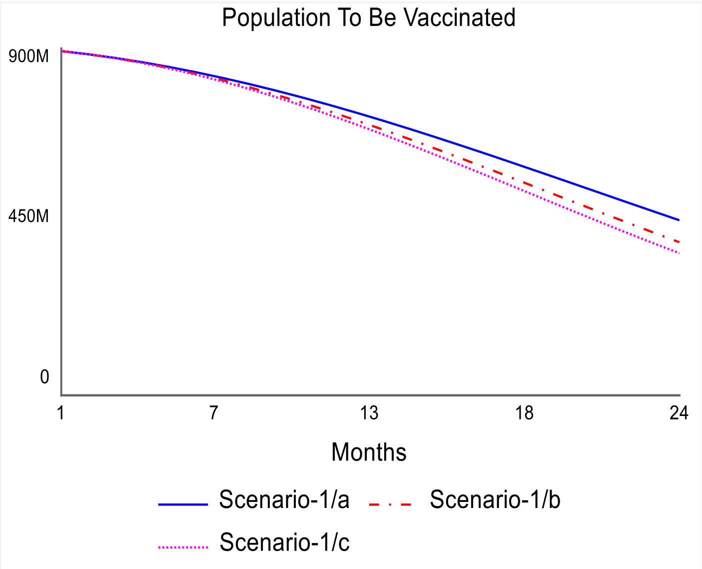
As shown in Table 2, three scenarios are formulated based on the Governance Index, Logistic Performance Index, and Vaccine Supply. For each scenario we created, three different situations are considered: Status Quo, World, and South Africa examples.

Script trials; Separately for each of the Governance Index, Logistic Performance Index and Vaccine Supply variables; If the current status quo, which we call the usual situation, continues, it has been simulated how the vaccine access situation in the African continent, the vaccine access situation in the South African example and how the vaccine access situation is affected based on the world averages. In terms of time, vaccine access status was observed in the light of scenarios within a period of 24 months.

In addition, a different scenario has been added in which the best case and the usual case, which consists of the most positive results obtained from the three scenarios and sub-scenarios, are compared. To put it more clearly; For the Governance Index (Scenario-1), the scenario with the best results was taken from the current status quo (a), South Africa (c) and World (b) sub-scenarios. Likewise, for the logistics performance index and vaccine supply, a scenario was created that compares with the usual situation, considering the values from which the best results are obtained from the a, b and c sub-scenarios.

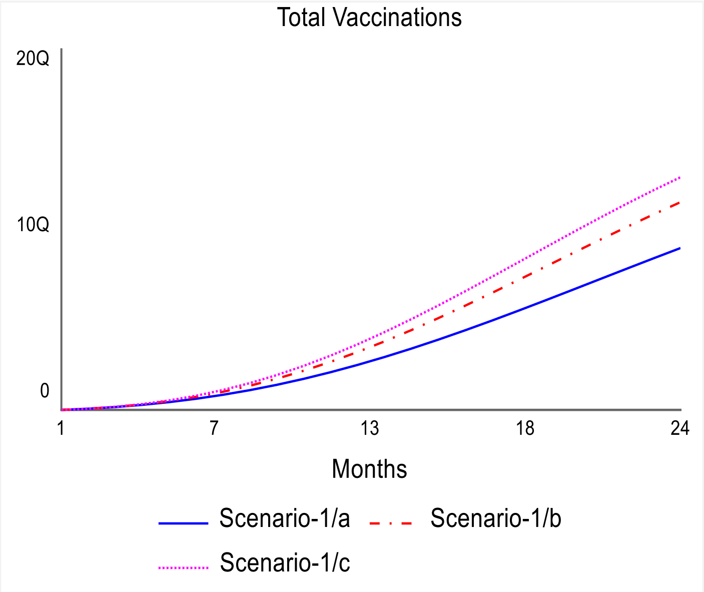
Finally, a scenario was implemented in which the effectiveness of the governance index, logistics performance index and vaccine supply variables on vaccine access was compared among themselves. The purpose of applying this scenario is to reveal the variable that most affects vaccine access among these three variables.

Figure 3. Scenario One: Population to be Vaccinated



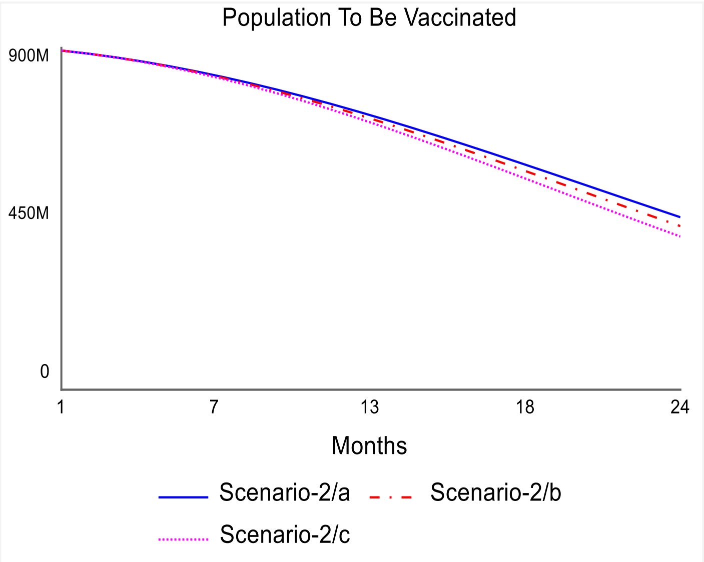
From Figure 3, it is understood from the first scenario governance index variable (a, b, c) that the population to be vaccinated has decreased at the end of 24 months in any case, but nearly half of the population to be vaccinated is still waiting for vaccination. Despite this, it is seen that the best results are obtained when the South African average governance index is achieved in vaccination rates in African countries.

Figure 4. Scenario One: Vaccine Access



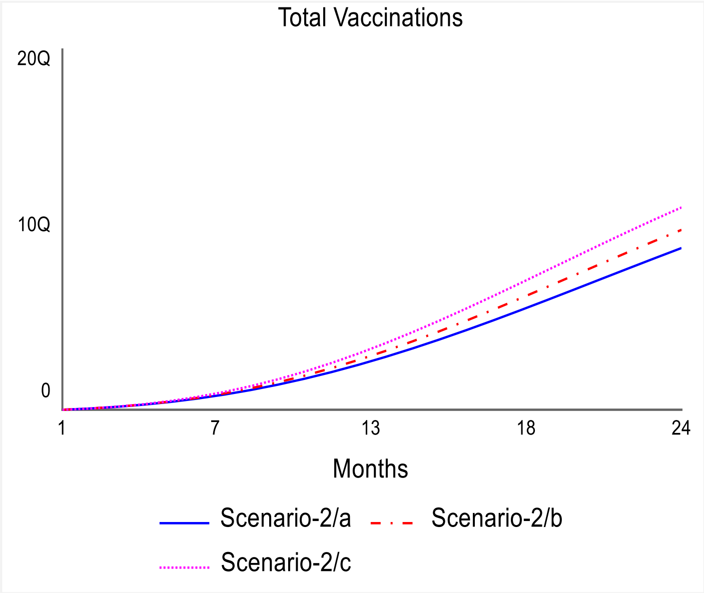
It is seen from Figure 4 that there is a clear difference between the world average and the South African average in the governance index variable in vaccine access compared to the African continent average, and that the goal of catching the South African average in vaccine access is the most real target.

Figure 5. Second Scenario: Population to be Vaccinated



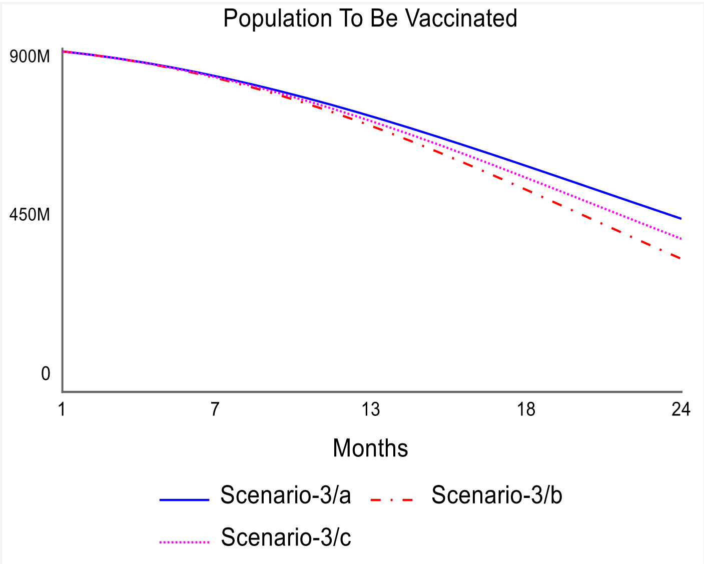
In the logistics performance index main scenario, it is seen in Figure 5 that the African continent average, the world average, and the South African average are all effective on the population that needs to be vaccinated, but they cannot reveal a serious vaccination difference between each other.

Figure 6. Scenario Two: Vaccine Access



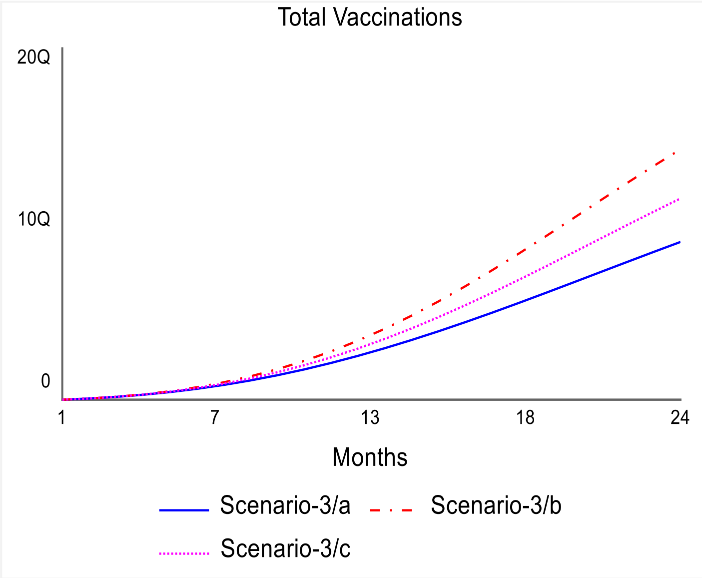
It is observed that the world average gives the best vaccine access result as a logistics performance index on vaccine range. Again, it is seen in Figure 6 that the African continent average has the least effect on vaccine access in its current state.

Figure 7: Scenario Three: Population to be vaccinate



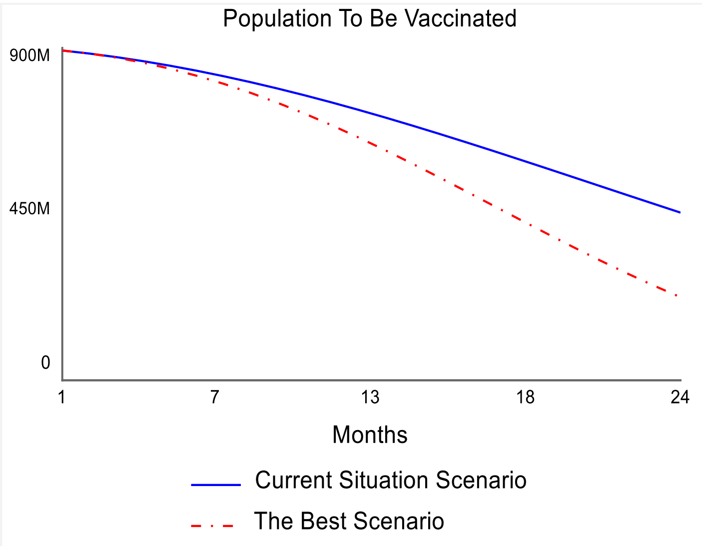
In this scenario, in which the African continent average, world average and South African average vaccine access impact of vaccine supply is examined as scenario 3, it is observed in Figure 7 and Figure 8 that the world average in vaccine supply gives the best results.

Figure 8. Vaccine Access



The catch of the world average in vaccine supply is seen in Figure 8, where it gives the best result in terms of vaccine access in the African continent. From this figure, it is clearly observed that there is a clear difference between the world average, the South African average, and the African continental average in vaccine supply.

Figure 9: Best Scenario: Population to be Vaccinated

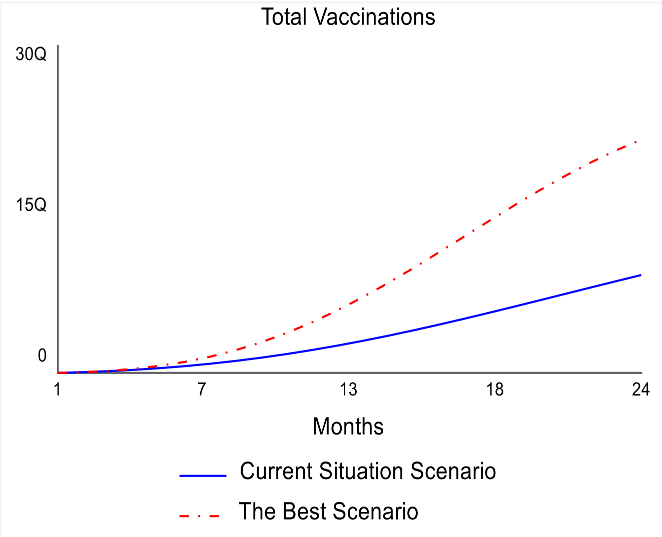


In the light of the data obtained as a result of the application of the first three scenarios, the scenario we created by taking the data with the best results among the variables and the scenario of the usual situation were compared in Figure 9. As the best data, the average of South Africa as the governance index and logistics performance index in the first and second scenarios, and the world average where the best result is obtained in the supply of vaccines in the third index, the best scenario is created and compared with the usual case scenario.

As seen in Figure 9, in the comparison between the usual situation scenario where the current situation is maintained and the best scenario with the best results, it is seen that there is a clear difference between the amount of population to be vaccinated at the end of 24 months. As a result of the best-case scenario, vaccine access appears to be more controlled.

The best-case scenario has been created by considering situations where optimal results are obtained from all applied scenarios. Figure 10 illustrates the total vaccination situation if the current situation continues in the best-case scenario.

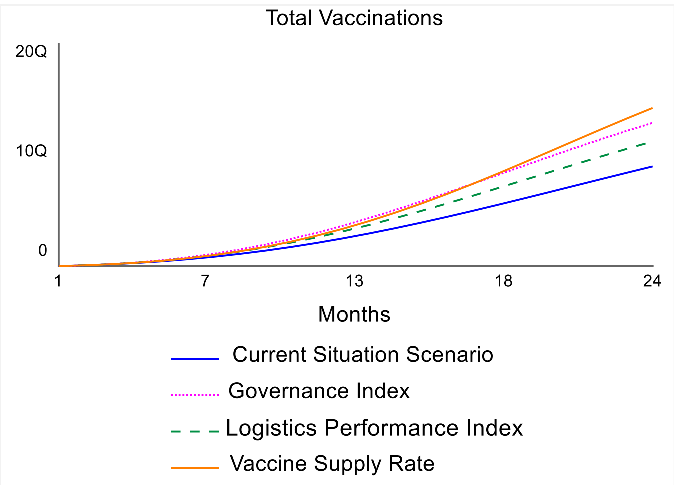
Figure 10. The Best Scenario: Vaccine Access



As seen in Figure 10, in the best-case scenario, there is a significant increase in total vaccination.

When the scenario created by considering the best results from all variables is applied; It is seen that the African continent, which is far below the world in terms of vaccine access, has reached a very good point in vaccine access at the end of 24 months. However, a one hundred percent point in vaccine access cannot be achieved. It is thought that other factors affecting vaccine access have an impact here.

Figure 11. Comparison of Variables Scenario: Vaccine Access



In this study, in which the variables of governance index, logistics performance index and vaccine supply, which are among the factors affecting vaccine access in the African continent, are examined, we have finally created a scenario that comparatively examines the effects of these variables on vaccine access. According to this scenario, the averages that most positively affect vaccine access were taken from these variables, and these variables were compared within themselves.

Accordingly, vaccine supply is the most important factor affecting vaccine access. No matter how good the governance index or logistics performance is, ensuring vaccine supply is the most important factor for vaccine access. Next comes the governance index. Considering these two situations, we can cite countries such as Israel and the United Arab Emirates as examples. Although both countries are low in the governance index, all their populations were vaccinated at the time of our study. Here, the importance of vaccine supply in vaccine access is demonstrated. Among all three variables, the logistic performance index has the least effect on vaccine access. However, it has a significant impact on vaccine access. We can clearly see this in Figure 11 when comparing the preservation of the current situation and the improvement in the logistics performance index.

4. FINDINGS

Nine scenario experiments have been conducted to examine how governance index, logistics infrastructure, and national income variables affect vaccination rates through the model of COVID-19 vaccine availability in the African continent. Several findings have been obtained as a result of these scenario experiments. Some of the findings are listed below:

-If the governance index catches the world average, at the end of 24 months, nearly 60% of the population cannot access the vaccine.

-When the governance index catches the South African average, the vaccination rate reaches 70%.

-When logistics performance and infrastructure improvement catch the world average, vaccination rates are close to 60%.

-When the logistics performance and infrastructure improvement catch the S. Africa average, a vaccination rate of up to 70% is achieved.

-Improvement in vaccine supply When the S. Africa average is achieved, 68% vaccination is achieved at the end of 24 months.

-When the world average is caught in vaccine supply, a vaccination rate of 74% is achieved at the end of 24 months.

-If the current status quo is maintained, vaccination rates remain below 50% at the end of 24 months. On the other hand, when the situations where the best result is obtained as a result of scenarios for each variable are considered together, a rate of 83% is achieved in vaccination rates.

5. CONCLUSION AND RECOMMENDATIONS

The findings show that vaccine availability, good governance index, and logistics factor are crucial factors in front of vaccination. Firstly, we indicated that vaccine availability is the most significant factor in front of vaccination. Secondly the governance index of states increases, people's access to vaccines increases. Therefore, in countries where political stability is ensured, violence is prevented, terrorism is minimized, corruption can be prevented, governments' effectiveness is increased, legal rules can be applied, responsibility and transparency are ensured, it is seen that access to the vaccine has a positive effect.

Finally, logistics performance and infrastructure strengthen, vaccine access increases. Here, the power of the logistics infrastructure makes it easier for people to access the vaccine. Logistics infrastructure has the effect of facilitating the supply of vaccines to the farthest corners of the country. This situation positively affects citizens' access to vaccines.

The variable that most impacts people's access to vaccines is the provision of vaccines. The most important factor here is related to the economic wealth of the country. Countries with high economic power are more advantageous in the supply of vaccines, and therefore they are more advanced than other countries in terms of their citizens' access to vaccines. Here, it is seen that the most effective variable in terms of citizens' access to vaccines is vaccine supply. It has been observed that the most important power affecting the vaccine supply is economic wealth. As an example, to this situation, it has been observed that although half of the people in the world have not been vaccinated yet, almost all citizens of the rich gulf countries and Israel have access to the vaccine. Although these countries are quite low in the governance index rankings and are in the middle ranks in the logistics performance index, they are at the forefront in the world in terms of vaccine access for all their citizens. Therefore, while the effect of other variables is not ignored, it is seen that the citizens of economically strong countries are more advantageous in accessing the vaccine.

The fact that healthy individuals contribute to the economy is a paramount indicator emphasizing that vaccination should not be viewed solely through the lens of public health. Vaccination, due to its role in fostering a healthy and productive population, also wields significant potential for boosting economic growth. Additionally, income levels emerge as the foremost factor influencing the achievement of widespread vaccination. It is observed that the rising economic prosperity of nations positively impacts both vaccine supply and the development of necessary logistics infrastructure essential for ensuring widespread vaccination. This is underscored by the ability of economically advanced nations to efficiently reach their citizens with vaccines, extending their vaccination efforts even into rural areas. This phenomenon underscores the close relationship between economic development and a well-established logistics infrastructure, demonstrating a mutually reinforcing causal relationship between vaccination and economic progress.

In an era where global trade and population mobility have advanced significantly, it is not an effective strategy for each country to rely solely on its own defense mechanisms and resources, limiting its efforts to within its borders, in the face of global pandemics. Prolonged isolationist approaches are nearly impossible in this interconnected world. Such a stance would disrupt international trade, supply chains, and international relations mechanisms, rendering a country economically paralyzed. Consequently, the economic impact on individuals would outweigh the consequences of pandemic disasters. Therefore, international organizations like the World Health Organization (WHO) should play a more effective and proactive role in combating such disasters. They should approach the issue comprehensively and coordinate infrastructure improvements that ensure access to healthcare services for all. Simultaneously, the establishment of a fund should provide financing for underdeveloped countries, without leaving this critical task to the discretion of individual governments.

As a result, the improvement of the logistics performance and infrastructure and the governance index, where other variables are not ignored and there is no shortage of supply, increases access to the vaccine in an equal and fair manner.

The study does not necessitate Ethics Committee permission.

The study has been crafted in adherence to the principles of research and publication ethics.

The authors declare that there exists no financial conflict of interest involving any institution, organization, or individual(s) associated with the article. Furthermore, there are no conflicts of interest among the authors themselves.

The authors declare that they all equally contributed to all processes of the research.

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APPENDIX:

INITIALIZATION EQUATIONS
: l Total_Cases = 9353563
TRANSIT TIME = 6
INFLOW LIMIT = INF
CAPACITY = INF
: c Deaths_Rate = 226,960/9353563*1/24
: s "\"Total_Second_Vaccineted_People\"" = 4,98/100/12*1275920972
: s People_Vaccinated = 9,03/100*1275920972
: s Population_To_Be_Vaccinated = 1275920972*7/10
: s The_Fully_Vaccinated_People = 0,06/100*1275920972
: s Total_Deaths = 226960
: s Vaccinations_Per_Hundred = 11/100*1/12
: c People_At_Second_Vaccinated_Per_Hundred = 5,2/100*1/12
: c Total_Population = 1275920972
: f "\"Second_Vaccinated\"" = People_At_Second_Vaccinated_Per_Hundred*Total_Population
: c People_Fully_Vaccinated_Per_Hundred = 0,06/100*1/12
: f Fully_Vaccinated = People_Fully_Vaccinated_Per_Hundred*Total_Population
: c Case_Rate = 9353563/1275920972*1/24
: f New_Cases = Total_Population*Case_Rate
: f Deaths = LEAKAGE OUTFLOW
: c Cases_To_Be_Vaccinated_Rate = 70/100
: f Cases_To_Be_Vaccinated = CONVEYOR OUTFLOW
: f New_People_Vaccinated_Smooted = Population_To_Be_Vaccinated*Vaccinations_Per_Hundred
: c Vaccine_Supply_Rate = 11/100*1/12
: c Governance_Index&Vacine_Supply_Rate = 30,425
: c Governance_Index = 0,0000274
: c Logistics_Performence_Index = 2,245
: c Logistic_Performance_Index&Vaccine_Supply_Rate = 0,034/100
: f Vaccine_Supply =
Vaccine_Supply_Rate*Vaccinations_Per_Hundred+Governance_Index&Vacine_Supply_Rate*Governance_Index+Logistics_Performence_Index*Logistic_Performance_Index&Vaccine_Supply_Rate
: c Amount_Of_Vaccinations_Required = 2
: c "Total_Populaton/Population_To_Be_Vaccinated" =
Population_To_Be_Vaccinated/Total_Population
: c Total_Vaccinations =
302590+The_Fully_Vaccinated_People+People_Vaccinated+"\"Total_Second_Vaccineted_People\""
: c Total_Vaccinations_Demand = Population_To_Be_Vaccinated*Amount_Of_Vaccinations_Required

{ RUNTIME EQUATIONS }
: s "\"Total_Second_Vaccineted_People\""(t) = "\"Total_Second_Vaccineted_People\""(t - dt) + ("\"Second_Vaccinated\"") * dt {NON-NEGATIVE}
: s People_Vaccinated(t) = People_Vaccinated(t - dt) + (New_People_Vaccinated_Smooted) * dt {NON-NEGATIVE}
: s Population_To_Be_Vaccinated(t) = Population_To_Be_Vaccinated(t - dt) + (Cases_To_Be_Vaccinated - New_People_Vaccinated_Smooted) * dt {NON-NEGATIVE}
: s The_Fully_Vaccinated_People(t) = The_Fully_Vaccinated_People(t - dt) + (Fully_Vaccinated) * dt {NON-NEGATIVE}
: s Total_Deaths(t) = Total_Deaths(t - dt) + (Deaths) * dt {NON-NEGATIVE}
: s Vaccinations_Per_Hundred(t) = Vaccinations_Per_Hundred(t - dt) + (Vaccine_Supply) * dt {NON-NEGATIVE}
: l Total_Cases(t) = Total_Cases(t - dt) + (New_Cases - Cases_To_Be_Vaccinated - Deaths) * dt {CONVEYOR}
CONTINUOUS
ACCEPT MULTIPLE BATCHES
: c Deaths_Rate = 226,960/9353563*1/24
: c People_At_Second_Vaccinated_Per_Hundred = 5,2/100*1/12
: f "\"Second_Vaccinated\"" = People_At_Second_Vaccinated_Per_Hundred*Total_Population {UNIFLOW}
: c People_Fully_Vaccinated_Per_Hundred = 0,06/100*1/12
: f Fully_Vaccinated = People_Fully_Vaccinated_Per_Hundred*Total_Population {UNIFLOW}
: c Case_Rate = 9353563/1275920972*1/24
: f New_Cases = Total_Population*Case_Rate {UNIFLOW}
: f Deaths = LEAKAGE OUTFLOW
LEAKAGE FRACTION = Total_Cases*Deaths_Rate
LINEAR LEAKAGE
LEAK ZONE = 0% to 100%
: c Cases_To_Be_Vaccinated_Rate = 70/100
: f Cases_To_Be_Vaccinated = CONVEYOR OUTFLOW
INFLOW MULTIPLIER = Cases_To_Be_Vaccinated_Rate*Total_Cases
: f New_People_Vaccinated_Smooted = Population_To_Be_Vaccinated*Vaccinations_Per_Hundred {UNIFLOW}
INFLOW MULTIPLIER = Population_To_Be_Vaccinated*Vaccinations_Per_Hundred
: c Vaccine_Supply_Rate = 11/100*1/12
: c Logistic_Performance_Index&Vaccine_Supply_Rate = 0,034/100
: f Vaccine_Supply = Vaccine_Supply_Rate*Vaccinations_Per_Hundred+Governance_Index&Vacine_Supply_Rate*Governance_Index+Logistics_Performence_Index*Logistic_Performance_Index&Vaccine_Supply_Rate {UNIFLOW}
: c "Total_Populaton/Population_To_Be_Vaccinated" = Population_To_Be_Vaccinated/Total_Population
: c Total_Vaccinations = 302590+The_Fully_Vaccinated_People+People_Vaccinated+"\"Total_Second_Vaccineted_People\""
: c Total_Vaccinations_Demand = Population_To_Be_Vaccinated*Amount_Of_Vaccinations_Required

{ TIME SPECS }
STARTTIME=1
STOPTIME=24
DT=1
INTEGRATION=EULER
RUNMODE=NORMAL
PAUSEINTERVAL=0