Simulation of Dynamic System to Assist Policy Formulation and Prevention and Mitigation Strategies Spread of COVID-19 in Medan

Meilita Tryana Sembiring, Sawaluddin, Anggi Ridho Habibie
Department of Industrial Engineering
Universitas Sumatera Utara
Medan, 20155, Indonesia
meilita@usu.ac.id, sawaluddin2501@gmail.com, anggiridhohabibi@gmail.com

Wahyudi Sutopo
Professor, Department of Industrial Engineering
Past Head of Department of Industrial Engineering
Head of Industrial Engineering and Techno-Economics Research Group
Vice Dean for Human Resources, Finance, and Logistics
Faculty of Engineering
Universitas Sebelas Maret (UNS), Surakarta, Indonesia
President, IEOM Indonesia Chapter
wahyudisutopo@staff.uns.ac.id

Abstract

The COVID-19 pandemic has spread to all corners of the world, including Indonesia. In this study, we will design a model for the spread of the COVID-19 pandemic in North Sumatra, to predict the number of patients, both ODP, PDP, positive, recovered or death and the capacity of hospitals to cope with the growing wave of COVID-19 victims. The preventive measures taken by the government in tackling this pandemic case are used as a scenario to see the extent to which these actions affect the number of patients and hospital capacity. This study uses a dynamic system method in designing the spread of the COVID-19 pandemic using AnyLogic Software. Experimental simulations were carried out with 3 different scenarios based on the coefficient value of the preventive action taken by the government if it was increased or decreased by 10%. The results of the simulations and scenarios show that the government's preventive measures are very influential in increasing or decreasing the number of infected patients and hospital capacity. Prevention measures that are reduced by the coefficient value by 10% lead to an increase in the number of patients and a significant decrease in hospital capacity significantly.

Keywords
Modeling, COVID-19, Dynamic System, AnyLogic

1. Introduction
The World Health Organization (WHO) or the World Health Organization declared COVID-19 as a pandemic on March 11, 2020, after the virus spread to almost all parts of the world. As of May 5, 2020, this virus has spread to 212 countries, and the most affected areas are the United States and most countries on the European continent such as Italy, France, Spain, and the UK. Indonesia itself is the region in Southeast Asia with the highest number of positive cases of COVID-19 as of May 5, 2020, as many as 12,071, and the death toll is 872 people.
Many dynamic model approaches have been taken to address the COVID-19 pandemic most previous studies only used the SEIR model as the basis for forming mathematical modeling logic based on existing data. A simple model

limited to SEIR can usually only predict the number of victims, but cannot predict other important variables such as the number of hospital capacities needed, the effect of preventive measures taken by the government, and the period of the virus cycle from infecting a susceptible population to being infected, then either recover or die.

The dynamic system is used in this study to model the spread of the COVID-19 pandemic in the form of a causal loop and form a simulation of a complex interconnected system, starting from the entry of several Imported Case populations from the entrance of the area, to forming an ODP population (Person Under Supervision) and PDP (Patient Under Supervision) which will then be declared positive, negative, or unconfirmed based on data from the percentage of PCR tests performed. The population of ODP and PDP will continue to grow along with the limitations of the PCR Test which cannot cover the entire population of ODP and PDP and can lead to an increase in the number of vulnerable victims exposed, thereby increase the population of local transmission.

In addition to predict the number of victims based on simulations and several scenarios carried out, this study will also predict the capacity needs of hospitals and their facilities such as the availability of PPE, beds, health workers, and ventilators. This study also looks at several prevention scenarios that the government can do such as limited access to airports and ports (Border Restriction), closing schools and offices by promoting learn and work from home programs, increase the number of PCR (Polymerase Chain Reaction) test to improve the handling of positive patients, as well as increase the availability of facilities at COVID-19 hospitals.

The ultimate goal of this research is to be able to design a tool that can effectively and efficiently summarize the problems that arise due to the COVID-19 outbreak related to the number of patients, health service capacity, and the effect of government preventive measures in an area. These tools are expected to be able to see the number of infected patient populations, the availability of health service capacity, as well as the influence of preventive movements by the government against the COVID-19 pandemic which is currently endemic by adjust the data announced by the government for the region, and in this study the region, The focus for research in North Sumatra Province, Indonesia.

1.1 Objectives

The general purpose of this study was to obtain a model for the spread and number of COVID-19 patients in North Sumatra using a dynamic system. The specific objectives of this research are as follows:

1. Obtain a conceptual design of a dynamic model to predict the spread and number of COVID-19 patients in North Sumatra by using a Causal Loop Diagram.
2. Obtain a simulation model of the spread and number of COVID-19 patients in North Sumatra using AnyLogic
3. Obtain an experimental simulation of the government's preventive measures against COVID-19 using several simulation model scenarios.
4. Obtain an analysis of the capacity needs of health services based on predictions of the spread and number of patients from the simulation results and several scenarios carried out.

2. Literature Review

Infectious disease modeling is a tool that has been used to study the mechanisms of disease spread, predict future outbreaks and evaluate strategies to control epidemics. Originally, dynamic models for infectious disease are largely based on compartmental structures and later developed by many other biologists. To formulate dynamic models for epidemic disease transmission, the population in an area is often divided into different groups or compartments. The model that describes the dynamic relationship between these compartments is called the compartment model.

The estimation of the spread of COVID-19 by developing a dynamic model of the epidemic based on a framework built with the SEIR method (Susceptible, Exposed, Infected, and Recovered) by looking at the change in the average contact rate per person as more deaths are reported in Iran. Then we look at the differences between reported cases and real cases by including the formulation and how these compartments change in response to the development of the epidemic. The following is a representation of the model built in this study.

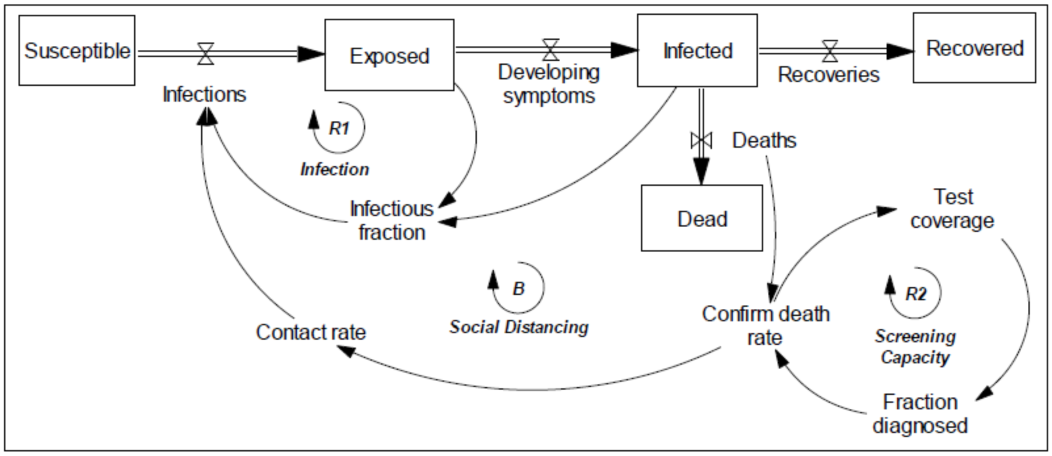

Figure 1. Simplified Model Representation

AnyLogic software supports the design and simulation of feedback structures such as stock and flow diagrams and array variables in a way that is easily recognizable to most system dynamics modelers. AnyLogic software offers all the benefits of an object-oriented approach to system dynamics modeling simply. Complex models can be defined continuously with objects simply by setting interface variables as inputs and outputs.

System analysis is closely related to the formation of a model of the system. The model is defined as a representation of the real system in a simple form involving only the most influential components. The model is used as a tool to analyze the existing system. The use of models in the engineering field is related to the natural world while the engineering field is related to the world of human creation.

System dynamics is defined as a field for understanding how things change over time. System dynamics is a method that can describe the process, behavior, and complexity in the system. This system dynamics methodology has been and is being developed since it was first introduced by Jay W. Forester in the 1950s as a method of solving complex problems that arise due to the causal dependence of various variables in the system. A causal loop diagram is an expression of a causal relationship in a particular picture. One of the elements of cause and effect refers to a qualitative (perceived) or quantitative (actual) measurable state. The process (rate) or information about the state as a cause that produces a state (level) or influence on the process as a result or preferably. A simulation is a tool that is only used if there is a natural understanding of the problem to be solved. Simulation is designed to help solve a problem related to a system that operates naturally. Failure in simulation experiments to produce a result is more often due to a lack of an understanding of the system than a knowledge of how to use simulation software.

3. Methods

The time of the study was carried out from March to July 2020 by looking at the development of the situation of the spread of COVID-19 which was updated every day. The type of research used in this study is a case study. Case study research is a research method that investigates phenomena in real-life contexts when the boundaries between phenomena do not appear clear or clear using various sources. The objects studied in this study were the number of patients who were ODP, PDP, positive, recovered, or died, the availability of hospital facilities, and the effect of preventive measures taken by the government in dealing with the COVID-19 pandemic that occurred. The variables in this study are divided into 3 types, namely the dependent variable, the independent variable, and the intervening variable. The variables needed in modeling the number of victims of the COVID-19 pandemic.

A conceptual framework is a form of framework that can be used as an approach in solving problems. Usually, the conceptual framework of this research uses a scientific approach and shows the relationship between variables in the analysis process. Research can be carried out if there is a good conceptual framework design so that the research steps are more systematic. The Research Conceptual Framework can be seen in Figure 1.

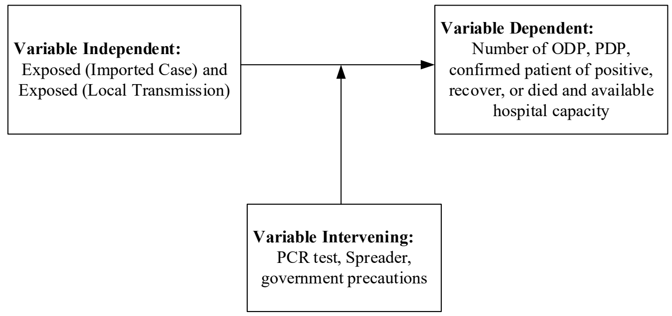

Figure 2. Research Conceptual Framework

4. Data Collection

The data collected for use in this study are as follows:

- Primary data is data obtained by conducted telephone interviews with doctors, nurses, or health workers who treat COVID-19 patients in North Sumatra to find out the latest information on the impact of the spread of COVID-19 in North Sumatra.
- Secondary data is data obtained from the Ministry of Health, North Sumatra Province Health Office, and the Central Statistics Agency of North Sumatra Province, namely data such as the number of ODP, PDP, Positive, Recovered, or Died Patients, and Hospital Capacity in handling the pandemic of COVID-19 in North Sumatra.
- Data collected for ODP, PDP, Positive, Recovered, or Died is limited according to the research limitations, namely data announced on April 20, 2020, to April 30, 2020, as well as Hospital Capacity data, which is available in March and April 2020.

Data processing is carried out in the design of the COVID-19 pandemic modeling in North Sumatra with a dynamic system model, namely:

- Build a conceptual model of the COVID-19 pandemic in North Sumatra with causal loop diagrams.
- Build a simulation model for the COVID-19 pandemic in North Sumatra in the form of stock and flow diagrams using AnyLogic Software.
- Verify and validate the model.
- Conducting experimental simulations on simulation models with scenarios in the form of preventive actions taken by the government.
- Calculate the value of the availability of hospital facilities.

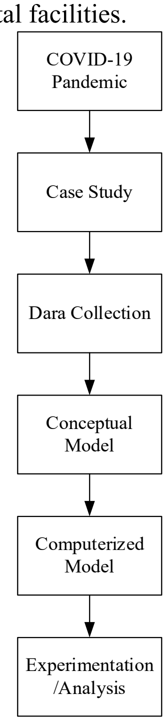

Figure 3. Research Block Diagram

5. Results and Discussion

Based on the dynamic system design Steps according to Forrester, the following are the dynamic system design procedures applied in this study:

- Describe the system to be designed using a causal loop diagram.
- Convert the system description into levels and rates and form a formulation equation using stock and flow diagrams in AnyLogic Software.
- Simulate a model that has been converted and formulated with AnyLogic Software.
- Design alternative policies and structures for testing by applying multiple scenarios to the model.
- Educate and discuss the model that has been tested by analyzing the simulation test model and the scenario results obtained.
- Implement changes to policies and structures that have been tested by providing discussions in the form of inputs and suggestions based on the results of simulations and model scenarios.

Causal loops are used to help modelers understand the system by providing an overview through cause and effect relationships in the system (system conceptualization). After all the required compartments, variables, and parameters are detailed, designed, and connected with a causal loop diagram, the results of the overall COVID-19 pandemic modeling design can be seen with the causal loop diagram in Figure 4 below.

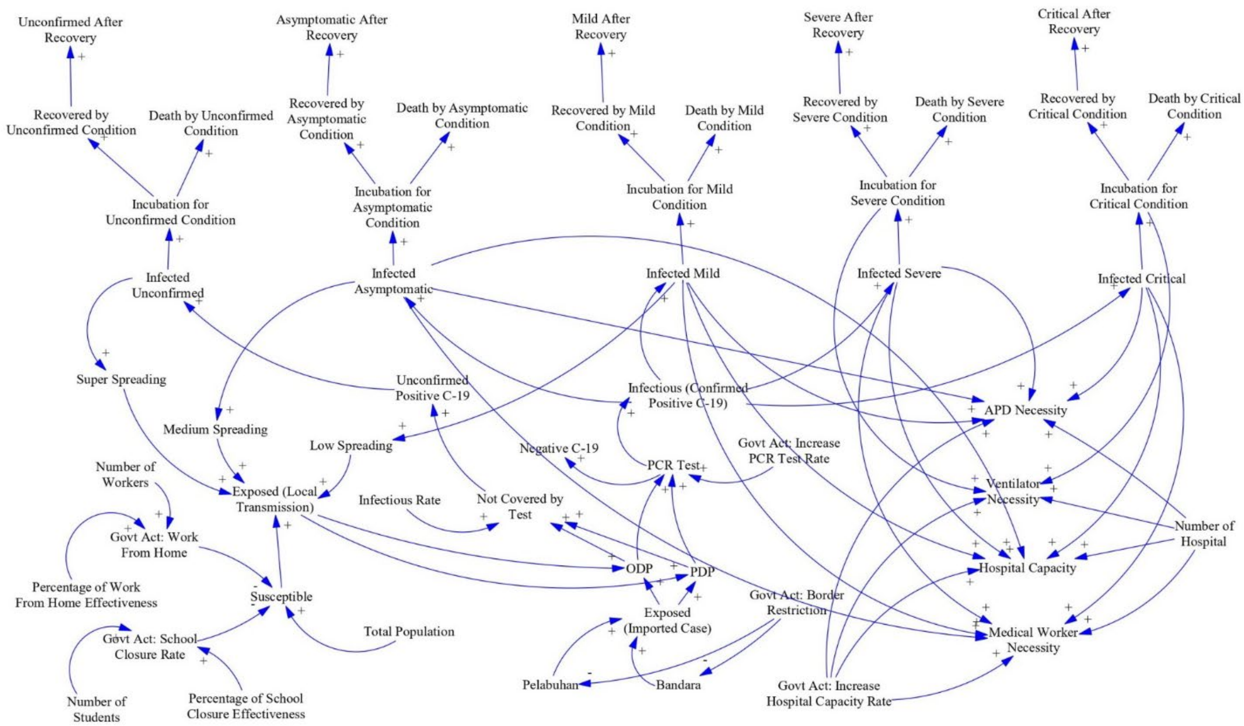

Figure 4. Causal Loop Overall Model Design

The display of the COVID-19 pandemic simulation model in North Sumatra that has been compiled in AnyLogic Software based on the design of the causal loop diagram can be seen in Figure 5.

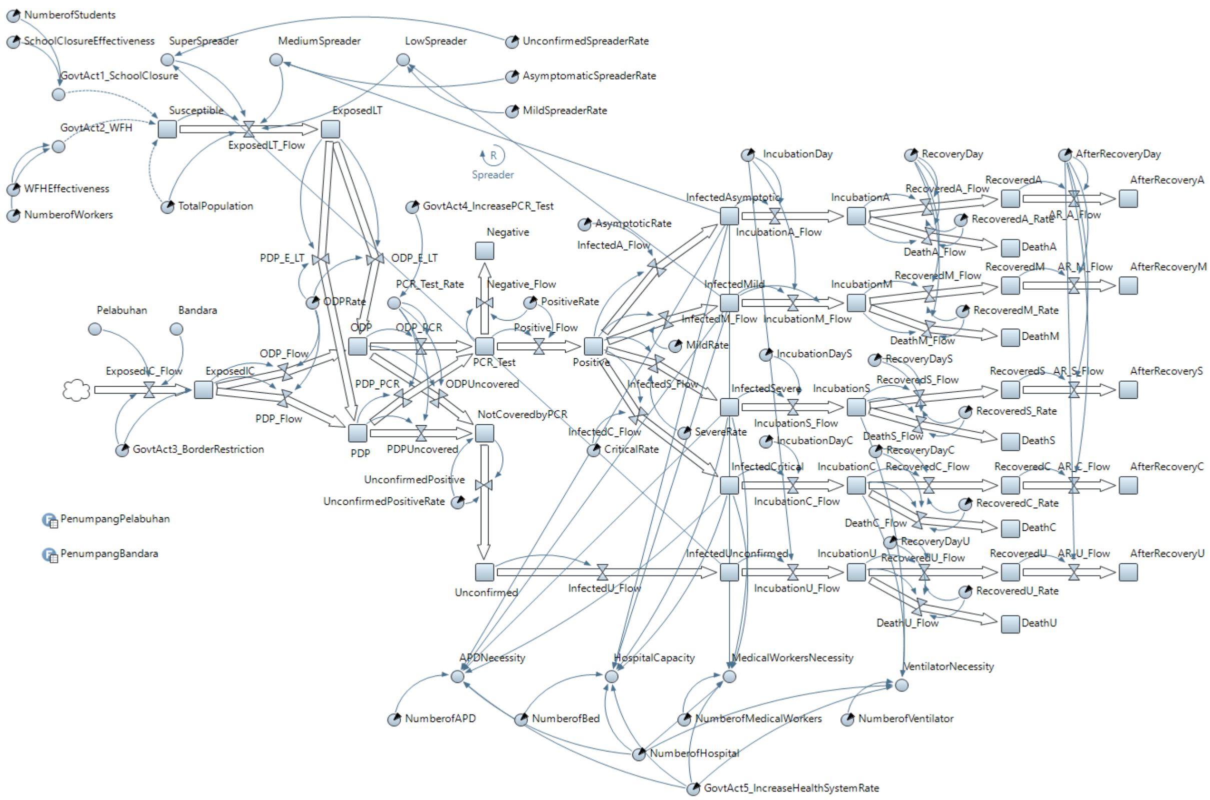

Figure 5. Simulation Model

After the simulation model is completed, a mathematical formulation is then drawn up using a computer language (programming language) and also from the data that has been collected. Then the model is verified which aims to ensure that the simulation model has been designed correctly by utilizing the Problems feature in AnyLogic Software to see if the designed model allows simulations to be carried out. If the designed model allows it to be simulated, it will show no error notifications and warnings on the problem features contained in the model. As can be seen in Figure 6 below.

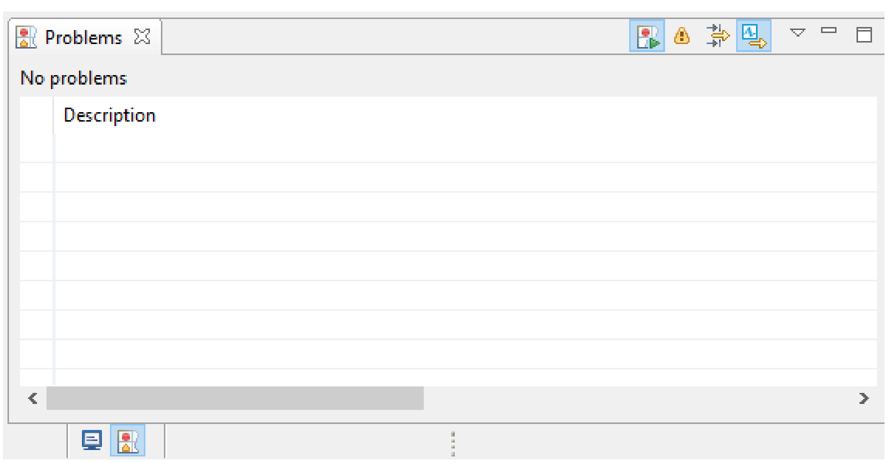

Figure 6. Feature Problems in the Simulation Model

After the model is verified, further validation is carried out on the model. Model validation is the process of determining whether the simulation model created can properly represent the real system. The model is said to be valid if the comparison results show that the model and the real system are not significantly different. Actual and simulated data on the number of ODP in North Sumatra from 20 April 2020 to 30 April 2020 can be seen in Table 1.

Table 1. Actual and Simulation Data on the Number of ODP in North Sumatra in 20 April 2020 to 30 April 2020

Date	Actual	Simulation	Date	Actual	Simulation
20 April 2020	1749	1976	26 April 2020	2443	2149
21 April 2020	1841	2005	27 April 2020	2412	2177
22 April 2020	2134	2035	28 April 2020	2403	2204
23 April 2020	2181	2064	29 April 2020	2401	2232
24 April 2020	2176	2093	30 April 2020	2341	2259
25 April 2020	2150	2121			

Model validation is done by testing the actual data with the simulation results. Whether the data is relevant or not. Validation on modeling can be done by comparing the behavior of the model with the real system, namely the MAPE (Mean Absolute Percentage Error) test. MAPE is a relative measure of the percentage error. This test can be used to determine the suitability of the simulation data with actual data.

$$\text{MAPE}=\frac{\sum\left|\frac{\text{A-S}}{\text{A}}\right|}{\text{n}} \text{ x } 100\%$$

The following is the MAPE calculation for ODP which can be seen in Table 2.

Table 2. Calculation of MAPE ODP

Date	Actual (A)	Simulation (S)	A - S	|A – S|	|(A - S)/A|
20 April 2020	1749	1976	-227	227	0,130
21 April 2020	1841	2005	-164	164	0,089
22 April 2020	2134	2035	99	99	0,046
23 April 2020	2181	2064	117	117	0,054
24 April 2020	2176	2093	83	83	0,038
25 April 2020	2150	2121	29	29	0,013
26 April 2020	2443	2149	294	294	0,120
27 April 2020	2412	2177	235	235	0,097
28 April 2020	2403	2204	199	199	0,083
29 April 2020	2401	2232	169	169	0,070
30 April 2020	2341	2259	82	82	0,035
Total	**24231**	**23315**	**916**	**1698**	**0,777**
				MAPE	**7,059**

There is a deviation of 7.059% between the simulation results and the actual data. Based on the model's accuracy criteria, the simulated MAPE value 5% < MAPE <10% so that it is said that the model is appropriate and acceptable (valid), as well as the value for PDP which is 6.964%, Positive Patient 5.047%, Patient Recovered 7.349%, and Patient Died 8.633%.

Data from the simulation results of Hospital Capacity handling COVID-19 based on the availability of PPE, beds, health workers, and ventilators in North Sumatra from April 20, 2020, to April 30, 2020, can be seen in Table 3.

Table 3. Data on Hospital Capacity Simulation Results

Date	APD	Sleeping Bed	Health Workers	Ventilator
20 April 2020	1074	73	-223	258
21 April 2020	1053	52	-244	248
22 April 2020	1033	32	-264	238
23 April 2020	1012	11	-285	228
24 April 2020	992	-8	-305	219
25 April 2020	972	-28	-325	208
26 April 2020	953	-47	-344	198
27 April 2020	933	-67	-364	188
28 April 2020	914	-86	-383	178
29 April 2020	895	-105	-402	167
30 April 2020	875	-125	-422	157

Experiments carried out on the simulation model aim to understand the behavior of the system concern the operation of the system. Simulation experiments in this study were carried out by creating several scenarios. The model simulation scenario in this study was carried out using government prevention, namely school closure, enforcing work from home, area border restrictions, increase PCR tests, and increase the capacity of health facilities. Scenarios are carried out by increased, decreased, or doing mixed actions on the parameter values of the coefficients of each of these precautions, then each scenario will be compared with the actual conditions and the initial validated simulation. Comparison of the simulation results of scenarios I, II, and III with the actual conditions and the initial simulation for ODP, PDP, Positive, Recovered, or Died Patients can be seen in Figure 7 below.

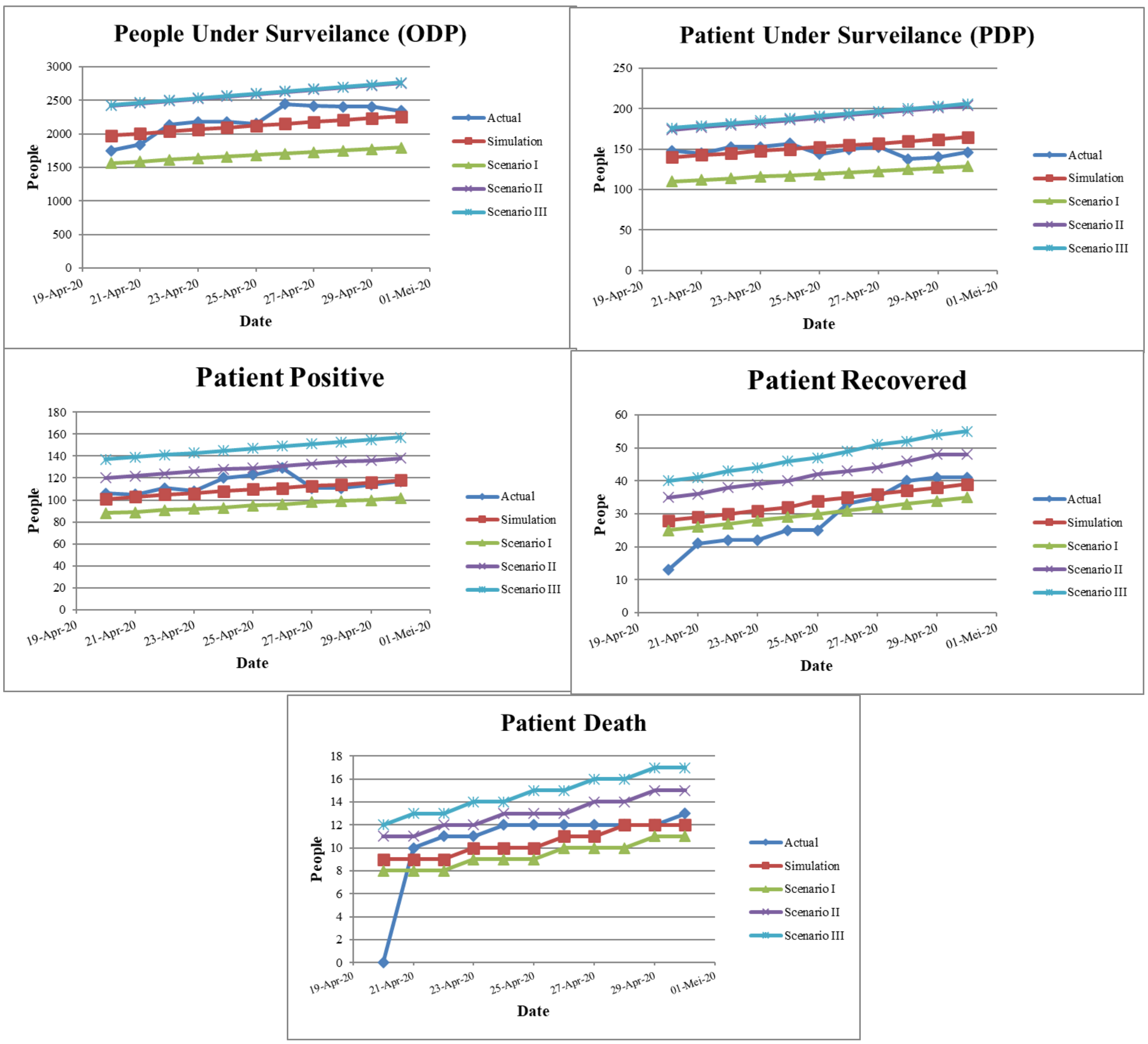

Figure 7. Comparison Graph of Actual Conditions and Initial Simulation
with the results of scenarios I, II, III

Comparison of the simulation results of scenarios I, II, and III with the initial simulation for Hospital Capacity which consists of PPE Availability, Bed Availability, Health Officer Availability, and Ventilator Availability can be seen in Figure 8 below.

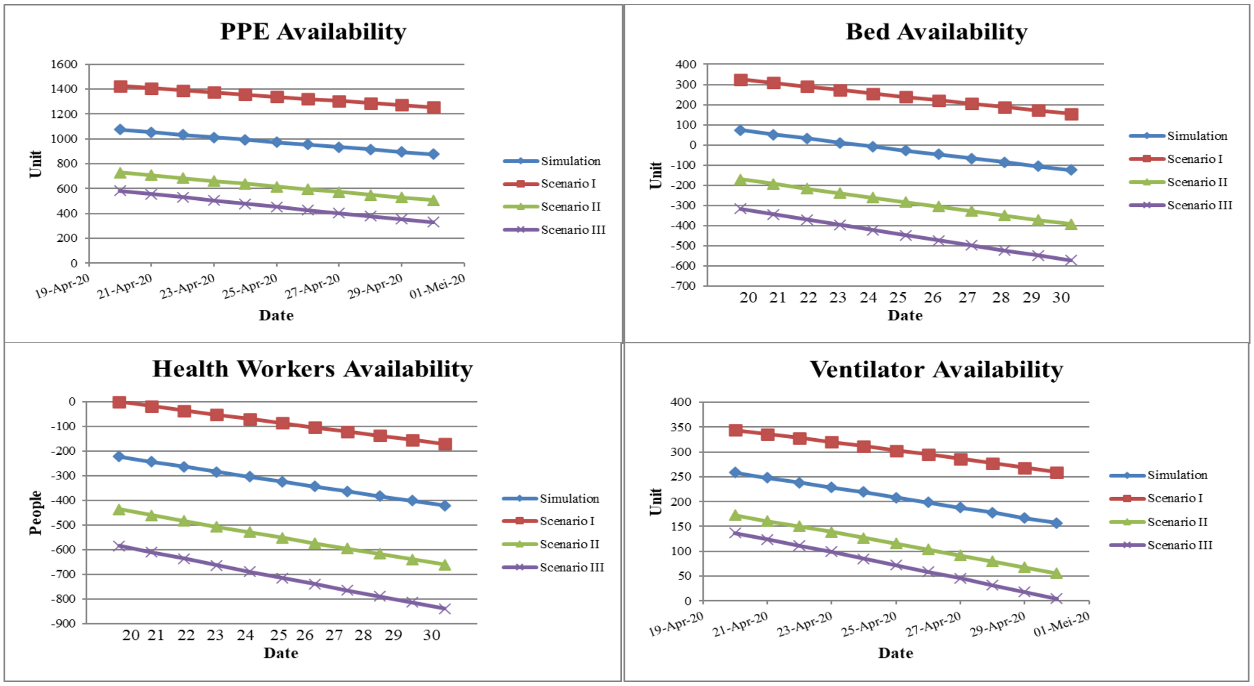

Figure 8. Comparison Graph of Initial Simulation with Scenario Results I, II, III

6. Conclusion

The conclusions that can be drawn from this research are as follows.

- Experimental simulations carried out using AnyLogic Software generate initial simulation values which are then validated with MAPE to match the actual data. Initial simulation values on April 30, 2020, resulted in 2259 ODP, 165 PDP, 118 Positive Patients, 39 recovered, and 12 died. The results of 3 scenarios of government preventive measures in which scenario I the coefficient value is reduced by 10%, scenario II is increased by 10% and scenario III is mixed by 10%, showing a decrease in the number of patients for the scenario I and an increase in patients for scenarios II and III. Successive scenarios (I, II, III) the number on April 30, 2020 is ODP (1797, 2752, 2762) people, PDP (129, 204, 206) people, Positive Patients (102, 138, 157) people, Healed (35, 48, 55) people, and Died (11, 15, 17) people.
- Hospital Capacity Simulation shows the availability of PPE, Beds, Health Officers, and Ventilators. Based on the initial simulation results on April 30, 2020, the availability of PPE amounted to 875 units, Beds -125 units, Health Officers -422 people, and Ventilator 157 units. As for the results of scenarios (I, II, III) on April 30, 2020, each of them shows the number of PPE availability (1256, 507, 329) units, Beds (155, -393, -571) units, Health Officers (-171, -660, -839 people, and Ventilator (259, 56, 5) units.
- Based on the scenario that has been carried out, it shows that preventive measures taken by the government can significantly affect the number of patients/victims as well as the available hospital capacity. The better the preventive measures taken by the government, the more significantly the number of patients/victims and increase the capacity of the hospital, conversely, the worse the preventive measures taken by the government, the more the number of patients/victims and reduced hospital capacity.

References

Arifin, M, Simulasi Sistem Industri, *Graha Ilmu*, Yogyakarta, 2009

Daley, D. J., & Gani, J., Epidemic Modelling: An Introduction, *Cambridge University Press*, New York, 2005

Forrester, J., System Dinamics, System Thinking and Soft OR., *System Dynamics Review,* vol. 10, no. 2-3 (Summer-Fall l994) 245-256, 1994.

Ghaffarzadegan, N., & Rahmandad, H., Simulation-based Estimation of the Spread of COVID-19 in Iran, *System Dynamics Review*, vol 36, No 1. 101–129, 2020.

Ma, Z., & Li, J., Dynamical Modeling and Analysis of Epidemics, *World Scientific Publishing*, Singapore, 2009.

Muhammadi, E., Aminullah, B., & Soesilo, Analisis Sistem Dinamis Lingkungan Hidup, Sosial, Ekonomi, Manajemen. *UMJ Press*, Jakarta, 2001.

Napitupulu, H. L., Simulasi Sistem Pemodelan dan Analisis, USU Press, Medan, 2009.

Nikulin et al., Using Dynamic Models and Empirical Covid-19 Data to Showcase Effective Pandemic Prevention Measures., *Worcester Polytechnic Institute Digital WPI*, 2020.

Peng et al., Epidemic analysis of COVID-19 in China by dynamical modeling, *Journal of Thoracic Disease,* 2020;12(3), 165-174, 2020.

Pornphol & Chittayasothorn, System Dynamics Model of COVID-19 Pandemic Situation: The Case of Phuket Thailand, *Proceedings of the 12th International Conference on Computer Modeling and Simulation*, 77–81, 2020.

Purnomo H., Pemodelan dan Simulasi untuk Pengelolaan Adaptif Sumberdaya Alam dan Lingkungan. *IPB Press*, Bogor, 2012

Rowell, D., & Wormley D. N., Systems Dynamics: An Introduction. *Prentice-Hall*, New Jersey, 1997

Shi et al., The impact of temperature and absolute humidity on the coronavirus disease 2019 (COVID-19) outbreak-evidence from China, *Preprint article from MedRXiv.com*, 2020.

Somantri, G. R., Memahami Metode Kualitatif. Makara, *Seri Sosial Humaniora*, 9 (2), 57-65, 2005.

Yang et al, Modified SEIR and AI prediction of the epidemics trend of COVID-19 in China under public health interventions*, Preprint article from MedRXiv.com*, 2020.

Biography

Dr. Ir. Meilita Tryana Sembiring, ST, MT received her Doctoral from Institut Pertanian Bogor (IPB) in 2015 and Masters Degree from Institut Teknologi Bandung (ITB) in 2004. Received her bachelor degree in Industrial Engineering and is currently an active lecturer since 1997 at the Department of Industrial Engineering, Engineering Faculty, Universitas Sumatra Utara. She is the Chairman of the Industrial Engineering Cooperation Agency (BKSTI) for North Sumatra - Aceh Region and is a member of the ISLI (Indonesian Supply Chain Association). Her main research interest is in Supply Chain Management (SCM). In one of her studies, Palm Oil Based Biodiesel Supply Chain Process Business Model, He has written dozens of Scopus-indexed research articles on processing in the palm oil sector and other fields. As a Principal Researcher at USU, she has received a total of several million grants from internal and government grants from her participation in community service activities. Her administrative experience shines even more when she was appointed as Chair of the Industrial Engineering Department for a period of five years from 2017 to 2022 and has successfully obtained coaching certification in 2020. Currently there are several PhD graduates and quite a number of Masters or other postgraduate who are currently working under her watch. She has also participated in the counterpart training of the Higher Education Development Support (HEDS) Project in Indonesia at Toyohashi University of Technology, Nagoya, Japan. She was also selected as a Program Examiner for Candidates for Civil Servants (CPNS) at several local universities.

Sawaluddin, ST received his bachelor's degree from the Universitas Sumatera Utara (USU) in 2019. Currently he believes as Assistant Lecturer at Department of Industrial Engineering, Engineering Faculty, Universitas Sumatra Utara and has actively contributed to helping activities in the Industrial Engineering Departement. During his time as a student, he served as Assistant Coordinator in Production Systems Laboratory (LSP, 2018-2019), Team Layout Editor Manager of the Industrial Engineering System Journal (JSTI, 2018-2019), member of Industrial Engineering Student Association (HIMTI FT USU, 2017-2019). Currently, he is the member of Industrial Engineering Alumni Association (HATIUSU, 2019-2022). In addition, he is also a leader in the team digital Industrial Engineering Program (DIGITECH, 2020-Present) and responsible for managing the website and social media of Industrial Engineering Department.

Anggi Ridho Habibi, ST, SS is a double degree fresh graduate from Industrial Engineering Universitas Sumatera Utara with GPA 3.46, and English Literature Universitas Harapan Medan with GPA 3.68. He was the Assistant Coordinator from Facility Layout and Material Handling Selection for the 2019/2020 period. In his third year, he had an Engineering Internship at PT. Agincourt Resources, a gold mine company located in Batang Toru, Sumatera Utara and was placed at Maintenance Department under the Planner Section. Currently, he is interested in learning more about Dinamic Modelling, Facility Layout, Material Handling, Supply Chain Management and Design Engineering.