Managing Medical Waste during COVID-19 Outbreak: A Simulation Approach

Agus Mulyadi and Niniet Indah Arvitrida
Industrial and Systems Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, 60111, Indonesia
agusmulyadi.18024@mhs.its.ac.id, niniet@ie.its.ac.id

Abstract

Medical Waste is a problem that existed before the Coronavirus Disease 2019 (COVID-19). The significant increase in Medical Waste during the COVID-19 outbreak causes these problems to become more urgent and complex because they relate to health, environmental, and economic problems in developing countries. Many interrelated factors influence the management of Medical Waste. A comprehensive analysis is needed to understand the complexity of the problem. This study aims to explore the right strategies and policies in dealing with the amount of Medical Waste during an outbreak such as COVID-19 and in ordinary (non-outbreak) conditions. The factors considered are demographic, operational of the waste generation, emergency, and cost and investment aspects. A Systems Dynamic approach is used in this study to structure the complexity of the problem comprehensively. This research consists of three stages; where the first stage was a preliminary study by conducting a field study, and the second stage was developing the model. The third stage was testing the model. A case study of Surabaya, Indonesia, is selected.

Keywords
Medical Waste, System Dynamics, COVID-19, Simulation, Waste Generation

1. Introduction

The catastrophic outbreak of the corona virus-19 (COVID-19) caused by Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) caused a significant impact in 213 countries in the world (Worldometer, 2020). The beginning of the spread occurred in Wuhan, China, in December 2019 (Rothan and Byrareddy, 2020). This disease has infected 12,685,374 cases with a death toll of 565,000 worldwide (WHO, 2020).

Besides impacting health and the economy (Susilawati et al., 2020), this virus also affects Medical Waste from handling COVID-19 patients. The Ministry of Health of the Republic of Indonesia stated an increase in Medical Waste by 30% from normal conditions. Medical Waste comes from hospitals from patients, including patients infected with COVID-19. The increase in medical waste is due to the increasing use of PPE (personal protective equipment), and most of it can only be used single-use, such as hazmat suits, masks, headgear, towels, gloves, and googles. Countries globally, especially developing countries, experience the same problem with managing Hazardous and toxic materials, Medical Waste. The ADB (2020), the increase in Medical Waste occurred by almost 500% from ordinary in April 2020. In Indonesia, through a survey conducted, Medical Waste increased from 13.6 tons/day or 0.96 kg/bed to 23 tons/day or 1.62 kg/bed (an increase of 46%) (IESA, 2020).

Management of Medical Waste is not a new problem in health, especially for developing countries (Chaerul et al., 2008). Improper handling of Medical Waste increases health and environmental risks because viruses can last a long time in materials such as PPE (Chin *et al.* 2020). Therefore, Medical Waste must be destroyed as soon as possible to avoid transmission, especially during the COVID-19 outbreak, because the infection rate for this type of virus is very high. Limited resources, such as processing incinerators, are the main challenges today, resulting in a gap between the generation of Medical Waste and a large processing capacity. In addition, the transportation of Medical Waste is also a significant concern at this time.

Therefore, Medical Waste management is the most pressing problem facing the government, especially in the COVID-19 outbreak. So this topic is an area of interest, and many researchers have researched this topic, such as Italy

(Cesaro and Pirozzi, 2020), India (Ranjan et al. 2020), China (Singh et al. 2020), Nigeria (Nzeadibe and Alieji, 2020) and Japan (Onoda, 2020).
This research aims to design and analyze alternative strategies and policies to deal with Medical Waste efficiently, especially during the COVID-19 outbreak. This study uses a System Dynamic simulation to structure the interrelationships between factors in managing Medical Waste comprehensively. The case study uses Surabaya, Indonesia, to present Medical Waste management for the same area.

2. Literature Review

Waste originating from health facilities is still poorly defined, so the terms are still used interchangeably. Such as infection medical waste (Wichapa and Khokhajaikiat, 2017), medical waste (Nikolic *et al.* (2016), Yu *et al.* (2020), Le *et al.* (2018)), Hazardous medical waste (Voudrias (2016)), hospital waste (Chaerul, Tanaka and Shekdar (2008), Wang *et al.* (2020), and biomedical waste (Ranjan et al. (2020). Because there is no universal use of these terms, in this study, Medical Waste is considered waste originating from health services and is by The Ministry of Health of Republic of Indonesian terminology.

Medical Waste management has a long process starting from sorting, collecting, transporting, processing, and disposal (Voudrias and Graikos, 2014). Much study has been completed on this topic as it relates to health and environmental issues. (Arab et al. (2017) analyzed the health impacts of cleaning workers from the waste collection in hospitals. Apart from that, sorting the Medical Waste can significantly reduce medical waste (Ciplak and Barton, 2012). On the downstream side of the process, scheduling and routing in Medical Waste collection use Mixed Integer Programming (Shih and Lin, 1999). In the downstream part of management, the waste treatment uses incinerators to destroy large amounts of Medical Waste (Almuneef and Memish, 2003). Until October 30, 2020, research on Medical Waste management during the COVID-19 outbreak was carried out a lot but only focused on management processes. The study conducted by Yu *et al.* (2020) designed a reverse logistics system to distribute Medical Waste effectively during the COVID-19 outbreak in Wuhan, China. Proper disinfection techniques can reduce the risk of health and environmental damage (Ilyas, Ranjan, and Kim, 2020).

The use of systems dynamics as a research method has solved many problems regarding Medical Waste management. The medical and domestic solid waste management model in Jakarta considers the NIMBY (not in my backyard) syndrome, which involves sub-system interactions between the population, budget, social, regulatory, and hospital management waste (Chaerul, Tanaka, and Shekdar (2008). Predicting the amount of Medical Waste from health facilities, both infectious and domestic waste, by considering beds, number of employees, and patients (Eleyan et al., 2013). Ciplak & Barton (2012) apply separation of the sources of Medical Waste, which impacts reducing the number of infections with a system dynamic. Ciplak (2013) uses system dynamics to predict health impacts on Medical Waste workers, especially in the incineration and landfill sections. As a result, the risk of death for incineration workers is high.

3. Methods

Systems Dynamics is an approach used as a modeling and simulation methodology to analyze long-term decision-making in management problems introduced by Jay Forester in the 1960s at the Massachusetts Institute of Technology (MIT). This approach is very suitable for solving complex problems by increasing understanding of the system's structure (Sterman, 2000). An example is the medical waste management system, such as the topic of this study. This approach helps modelers conceptualize and analyze complex systems' structure, interactions, and behavior in exploring, assessing, and determining their impact in an integrated and holistic manner (Chaerul et al., 2007).

This research consists of three main stages: the field study stage, the model development and simulation stage, the model testing stage, and the policy design and analysis stage.

3.1 Field Study Phase

At this stage, observation and initial identification of medical waste in the city of Surabaya was carried out, especially for the object of research, namely Medical Waste. The results of the study determine the formulation of the problem and research objectives. Then conduct a literature review on theories related to Medical Waste, processing, transportation, simulation concepts, and other theory relevant to the research topic. The data collected consists of primary data and secondary data. Preliminary data comes from the health office and the environment office of Surabaya by conducting interviews. Meanwhile, secondary data collection comes from the Surabaya city health and environmental office, the East Java health and environment office, the Central Statistics Agency, and the Surabaya Population and Civil Registry Office.

3.2 Model Development Phase

The conceptual model development stage is carried out based on actual conditions to present the system appropriately. The first stage identifies the variables that affect the Medical Waste management system. Then the conceptual model is developed by designing a causal loop diagram (CLD) of the identified variables. In CLD, there are elements and links to determine the cause and effect relationship between variables, namely positive or negative. Changes in variables produce changes in other variables in the same direction if the relationship is positive.

In contrast, if the relationship is negative, variables produce other variables in the opposite direction. In addition to the mark on each link, there is a feedback sign in case of a loop. The feedback loop consists of a positive or reinforcing loop and a negative or balancing loop. The loop sign is obtained by counting the number of negative signs (-) on the link that forms the loop. If the causal link is odd, the feedback loop is negative; conversely, the feedback loop is positive when the causal link is even. After describing the relationship between variables with the causal loop diagram, build a stock and flow diagram (SFD) design and a mathematical formulation of the interactions between variables. System Dynamics consists of several building blocks, namely stock, flows, connectors and converters. Stock (symbol: rectangle) is a status variable and represents the accumulation between variables, Flow or rate (symbol: valve) is the change stock, Connector (symbol: arrow) is a link of information representing cause and effect in the model structure, and converter (symbol: circle) is an intermediate variable used for calculations in the model.

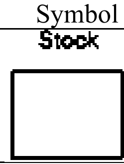
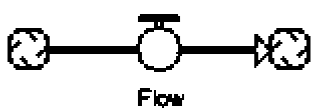
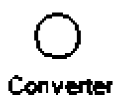
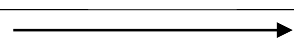
No	Symbol	Name	Definition
1		Stock	Cumulative of behavior
2		Flow	The Flow of material or information per time
3		Converter	Formulations that affect the output value
4		Connector	Send information

Figure 1. Stock and Flow Diagram Notation

3.3 Model Testing Phase

Verification and validation in model testing aim to determine the model built with the existing system is appropriate. Model verification determines the logical fit between the conceptual model and the model design. This stage is a structured walk-through, tracing the results by comparing the simulation results with hand calculations. Then evaluate the reasonability and plausibility of the output of the simulation. After verification, validate the model with several tests: the boundary adequacy test, the structure assessment test, the parameter assessment test, and the extreme condition test (Sterman, 2000). In addition, another validation test uses a black-box approach based on statistical analysis, namely the mean comparison test (Morecroft, 2015).

4. Result and Discussion

Surabaya has the second-higher number of COVID-19 infected cases in Indonesia, after Jakarta. The patient of COVID-19 infected has an impact on the amount of medical waste generated. During the COVID-19 outbreak, medical waste becomes two, namely medical waste handling COVID-19 (COVID-19 waste) and medical waste handling general patients (medical waste). The generation of COVID-19 waste began to occur when the first Covid-19 infection occurred in Surabaya, namely in March 2020, as shown in Figure 2, which is 9,932.38 kg. At the same time, the highest amount of COVID-19 waste generation occurred in July 2020 at 71,728, 24 kg. The amount of COVID-19 waste generation is directly proportional to the number of COVID-19 infections.

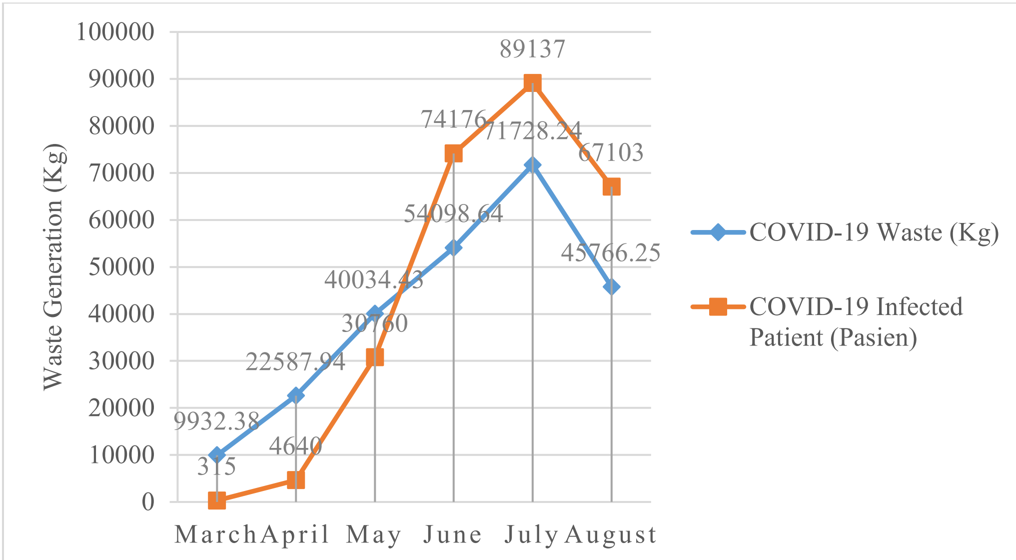


Figure 2. COVID-19 Waste and COVID-19 Infected in Surabaya

In addition to COVID-19 waste, several health centers experienced a significant increase in medical waste, especially in Surabaya. Health facilities in Surabaya are grouped into several types, namely hospitals, health centers, clinics, laboratories, pharmacies, and doctor/nurse/midwife practices. As seen in the table, in 2019 (before the outbreak), the total amount of medical waste produced was 7,326.7 kg/day. After the outbreak occurred, the increase became 14,691.58 kg/day, or an increase of 99.54%. The highest increase in medical waste occurred in laboratories by 322%; This was due to the laboratory being the center for checking COVID-19, such as swab/PCR/antigen tests that produce medical waste. As for the hospital, an increase of 41% from normal conditions follows a statement from the Indonesian Ministry of Environment and Forestry, which states that medical waste has increased by 30-50% (Violetta, 2020).

Table 1. Medical Waste Generation Before and After COVID-19 in Surabaya

No	Type of Hospital	Waste Generation (Kg/Days)		Percentage Change (%)
		Before	After	
1	Hospital	5.507,38	7.779,83	41
2	Public health centre	145,75	120,77	-17
3	Clinic	180,92	576,75	219
4	Laboratory	23,65	113,16	378
5	Pharmacy	325,94	1.111,92	241
6	Doctor/Nurse/Midwife Practice Practice	1.179,06	4.980,68	322
7	TGC Posts	0	8,47	100
TOTAL		7.362,7	14.691,58	99,54

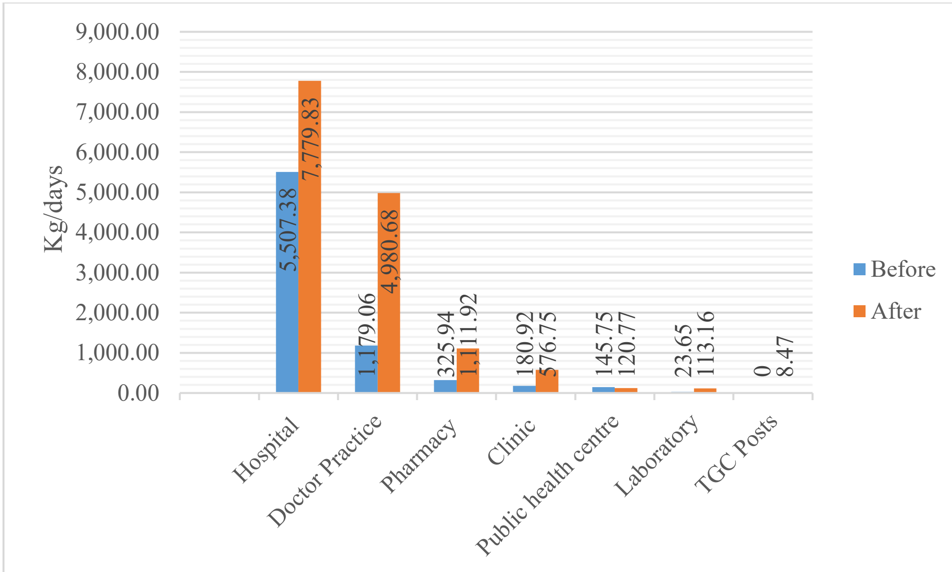


Figure 3. Medical Waste Generation Before and After COVID-19 Outbreak

The results of this study consist of the development of causal loop diagrams (CLD), stock and flow diagrams (SFD), and testing models. In this study, the CLD consists of four aspects: demographic, emergency, waste generation, and cost.

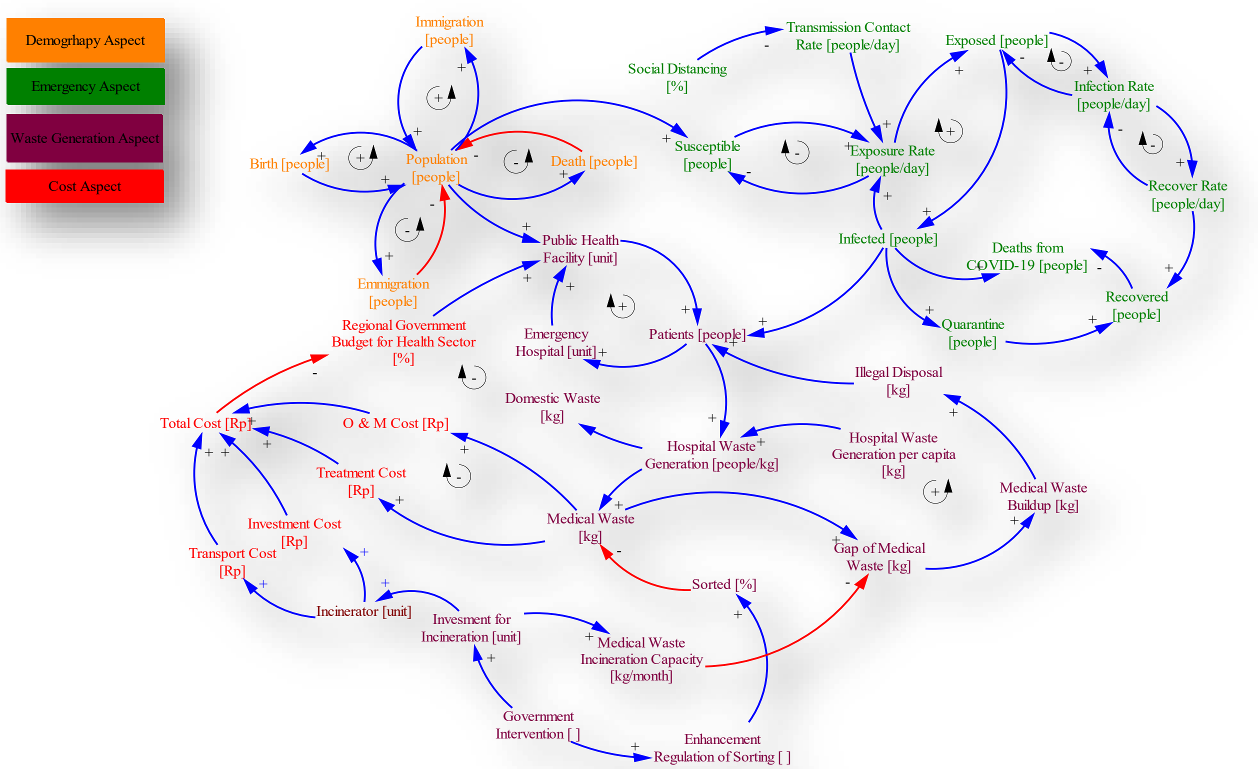


Figure 4.Causal Loop Diagram of
Medical Waste Management during COVID-19 Outbreak

The following table to obtain a comprehensive view of the relationship of each variable from all aspects.

Table 2. Causal and Impact in Each Variable

Aspect	Causal	Impact	Relationship
Demography	Population	Birth	Positive
	Population	Death	Negative
	Birth	Population	Positive
	Death	Population	Negative
	Immigration	Population	Positive
	Emigration	Population	Negative
Emergency	Susceptible	Exposure Rate	Positive
	Vaccination	Susceptible	Negative
	Exposure Rate	Susceptible	Negative
	Transmission Rate	Exposure Rate	Positive
	Exposure Rate	Exposed	Positive
	Exposed	Infection Rate	Positive
	Infection Rate	Exposed	Negative
	Infection Rate	Recover Rate	Positive
	Infection Rate	Infected	Positive
	Recover Rate	Infection Rate	Negative
	Recover Rate	Recovered	Positive
	Infected	Deaths from COVID-19	Positive
	Infected	Quarantine	Positive
	Recovered	Deaths from COVID-19	Negative
Waste Generation	Population	Public health facility	Positive
	Infected	Patients	Positive
	Public health facility	Patients	Positive
	Patients	emergency hospital	Positive
	emergency hospital	Public health facility	Positive
	Patients	Hospital Waste Generation	Positive
	Hospital Waste Generation	Domestic Waste	Positive
	Hospital Waste Generation per capita	Hospital Waste Generation	Positive
	Hospital Waste Generation	Medical Waste	Positive
	Medical Waste	Gap of Medical Waste	Positive
	Gap of Medical Waste	Medical Waste Buildup	Positive
	Medical Waste Buildup	Illegal Disposal	Positive
	Illegal Disposal	Patients	Positive
	Sorted	Medical Waste	Negative
	Enhancement Regulation of Sorting	Sorted	Positive
	Government Intervention	Enhancement Regulation of Sorting	Positive
	Government Intervention	Investment for Incineration	Positive
	Investment for Incineration	Medical Waste Incineration Capacity	Positive
	Medical Waste Incineration Capacity	Gap of Medical Waste	Negative
	Investment for Incineration	Incinerator	Positive
Cost	Incinerator	Transport Cost	Positive
	Incinerator	Investment Cost	Positive

	Investment Cost	Total Cost	Positive
	Transport Cost	Total Cost	Positive
	Medical Waste	O&M Cost	Positive
	Medical Waste	Treatment Cost	Positive
	O&M Cost	Total Cost	Positive
	Treatment Cost	Total Cost	Positive
	Total Cost	Regional Government Budget for Health Sector	Negative
	Regional Government Budget for Health Sector	Public health facility	Positive

The building model in the stock and flow diagram consists of four components, namely stock, rate, converter, and connector. The system dynamic simulation model consists of linear differential equations such as level equations, rate equations, assist equations, parameter equations, condition equations, and initial value equations in the stock and flow diagrams. The model consists of 4 aspects: the demographic aspect, the emergency aspect, the waste generation aspect, and the cost aspect. Each identified variable has a different formulation according to the general formulation, actual conditions, and related data.

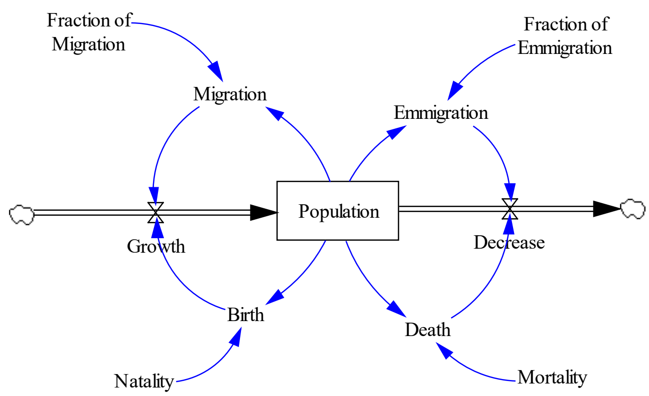


Figure 5. SFD of Demography Aspect

Medical Waste is generated from patient handling. In the aspect of waste generation, there is a Medical Waste stock. This stock is influenced directly by patients to health facilities such as hospitals and health centers in this study. These patients consist of two types, namely inpatients and outpatients. Apart from these types of patients, Medical Waste is also affected by COVID-19 patients, where the amount of waste produced is more per patient.

Inpatients and outpatients have a relationship with the population in the demographic aspect. In the demography aspect, four variables affect the population: birth, death, immigration, and emigration. At the same time, for COVID-19 patients using an outbreak disease spread model, namely SEIR (Susceptible-Exposed-Infected-Removed) model with policies related to COVID-19 in the city of Surabaya, namely social distancing and quarantine/isolation. The design of the SEIR model refers to several previous studies, namely (Clarissa et al., 2021) and (Sy et al., 2021). The basic model becomes an input value that projects the number of COVID-19 patients for 60 months. The SEIR model was modified according to the city of Surabaya.

Two processes reduce Medical Waste in health facilities in the waste generation aspect, namely the transportation and processing processes. The transportation process is strongly influenced by the vehicle's capacity, the frequency of transportation, and the distance traveled by the vehicle. Meanwhile, Medical Waste treatment destroys the waste by burning it at a specific temperature. Waste treatment is influenced by the incinerator's capacity, owned by health facilities and private processing companies' ability. There are four main costs in the cost aspect that affect waste management, namely O&M costs, treatment cost, investment costs, and transportation costs.

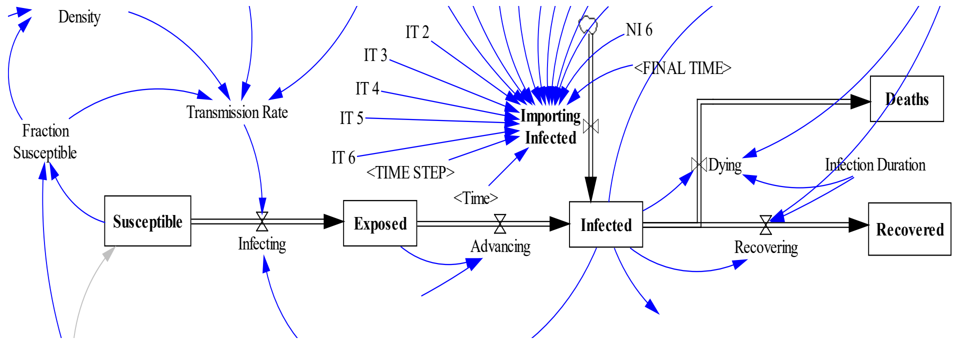


Figure 6. SFD of Emergency Aspect

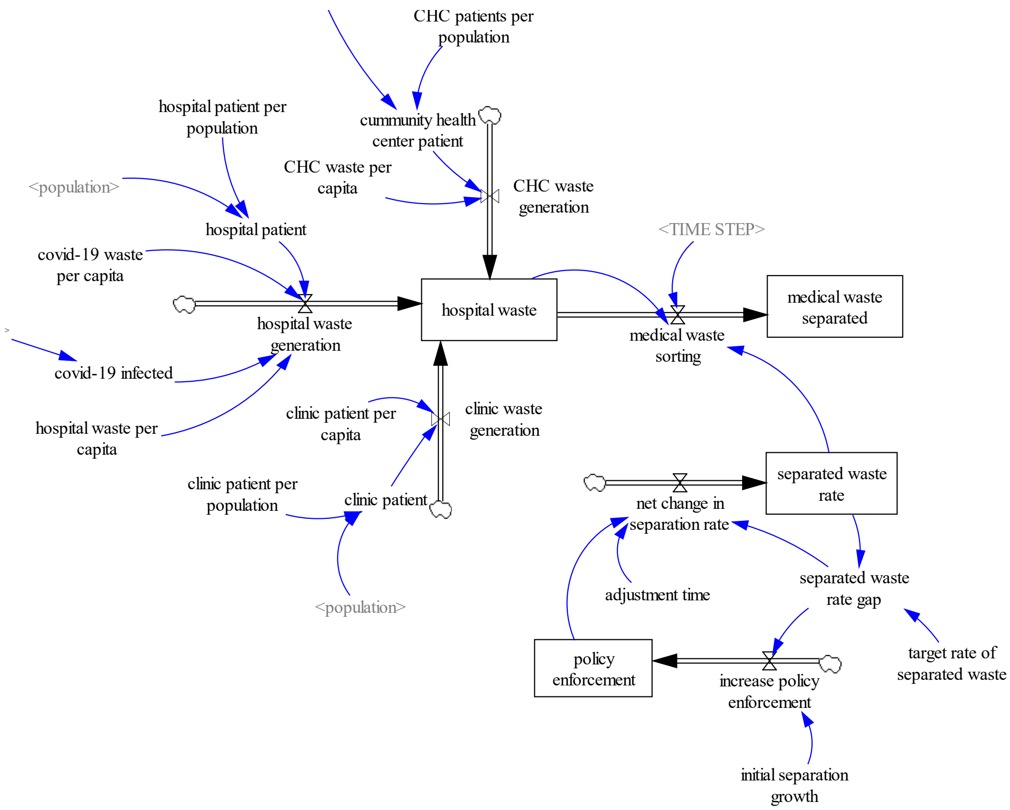


Figure 7. SFD of Waste Generation Aspect

Model design using VENSIM software, and the time horizon model is a monthly period of 60 months (5 years) from March 2020 to March 2025. The simulation results emphasize the waste generation, the number of transporters, and the special processing of Medical Waste. Apart from that, management costs are also involved in this research.

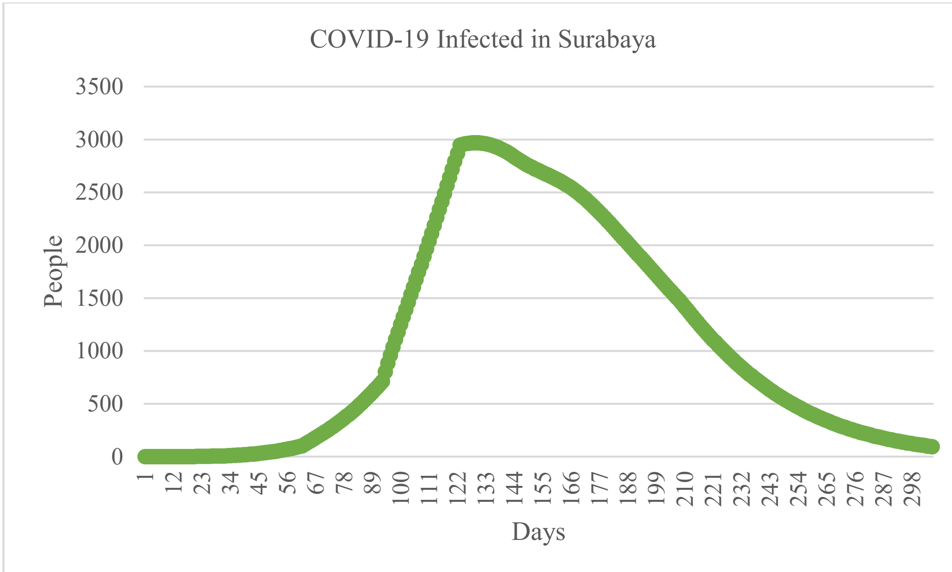


Figure 8. Result of Emergency Aspect

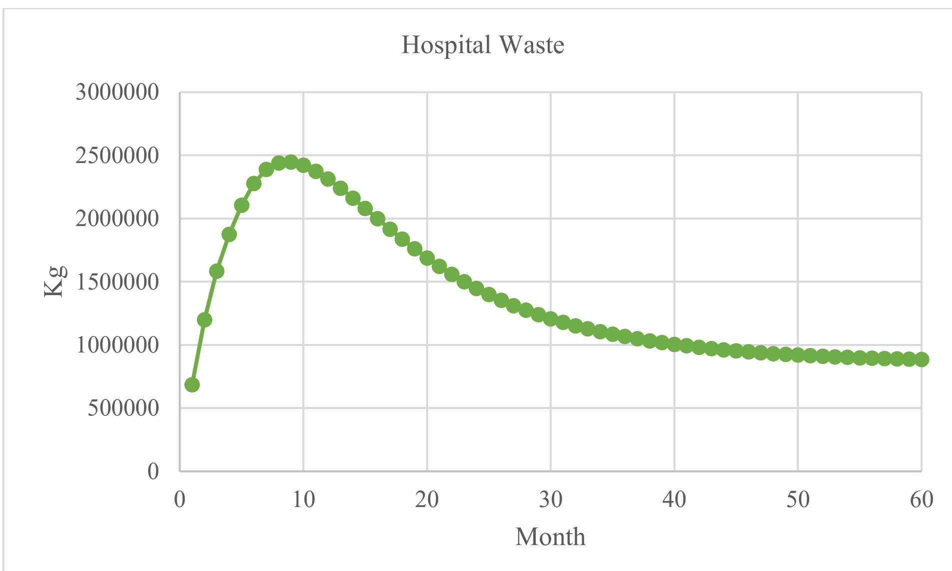


Figure 9. Result of Hospital Generation

Figure 8 is the result of a simulation of Covid-19 patients in Surabaya. This simulation uses the unit of time of day because the characteristics of the virus are challenging to model in months in the medical waste model. The outbreak occurred on March 16, 2020. From the simulation results, the peak occurred on the 149th day since the outbreak first occurred and ended on the 451st day. The number of people who were confirmed positive for COVID-19 at its highest peak was 2761 people.

Health care facilities produce waste in the form of medical waste and domestic waste. Figure 9 shows the peak of hospital waste due to the COVID-19 outbreak. But over time, hospital waste will begin to fall when the outbreak is over.

Meanwhile, the public health center has the smallest amount of Medical Waste, namely 3.623, 10 kg per month. In some health facilities, there are no inpatients. The operation is limited to minor procedures.

Model testing in system dynamics simulation consists of two ways, namely verification, and validation. Model verification can be done by checking the consistency of the units on the VENSIM software. Then the validation is carried out by the limit adequacy test through a literature review from the previous, through interviews with the health office and the environment office of the city of Surabaya. In addition, validation was carried out with MAPE (mean absolute percentage error), with an accepted error limit of 5%. The model can describe the actual conditions if the MAPE is <5%, whether between 5% to 10%, and false if the value is above 10% (Morecroft, 2015).

Table 2 Validation population of Surabaya

Month (2020)	Actual	Simulation	Error
March	3.169.847	3.169.847	0.00%
April	3.175.314	3.175.109	0.01%
May	3.180.791	3.180.380	0.01%
June	3.186.277	3.185.659	0.02%
July	3.191.773	3.190.947	0.03%
August	3.197.278	3.196.244	0.03%
September	3.202.793	3.201.550	0.04%
October	3.208.317	3.206.865	0.05%
November	3.213.851	3.212.188	0.05%
December	3.219.394	3.217.520	0.06%
Average Error			0.03%

Based on the table above, the error value in the total population is 0.00029 (0.03%), which defines the model as sufficient to represent the actual situation.

5. Conclusion

This study shows that the System Dynamics model is an appropriate simulation method in a complex Medical Waste management system. The model developed in the stock and flow diagram consists of 4 aspects: the demographic aspect, the emergency aspect, the waste generation aspect, and the cost aspect. The model was developed based on the COVID-19 referral hospital, non-referral hospital, health center, and clinics based on health services during the COVID-19 outbreak.

The system dynamic model can help plan to optimize the Medical Waste management system during the COVID-19 outbreak and ordinary conditions to reduce health and environmental risks. The more Medical Waste is processed, the more it will improve public health.

The COVID-19 referral hospital has more complete health facilities than other health facilities, so the amount of Medical Waste generated is also more significant. The COVID-19 referral hospital generates a generation of Medical Waste for hospitalization of 5.457,49 kg per day. In contrast, in non-referral hospitals, it is 2.322,34 kg per day, health centers, 120, 77 kg per day, and clinics, it is 576, 65 kg per day.

This research implies that the Surabaya city government can use the resulting model to address Medical Waste. The policy is in the form of the number of trucks, the type of processing technology, the number of processing equipment, and the percentage of the government budget for medical waste.

References

ADB. (2020). *Managing Infectious Medical Waste during the COVID-19 Outbreak*. Retrieved from https://www.adb.org/publications/managing-medical-waste-covid19

Almuneef, M., & Memish, Z. A. (2003). Effective medical waste management : It can be done. *American Journal of Infection Control*, *31*(3), 188–192.

Arab, M., Safari, H., Zandian, H., & Nodeh, F. H. (2017). Evaluation of practicing safety features for hospital waste collection among Iran's public hospitals. *Journal of Material Cycles and Waste Management*, *19*(2), 939–945.

Cesaro, A., & Pirozzi, F. (2020). About the effects of Covid-19 on solid waste management. *TeMa. Journal Of Land Use, Mobility and Environment*, 59–66.

Chaerul, M., Tanaka, M., & Shekdar, A. V. (2007). A system dynamics approach for hospital waste management. *Waste Management*, *28*(2008), 442–449.

Chin, A. W. H., Chu, J. T. S., Perera, M. R. A., Hui, K. P. Y., Yen, H., Chan, M. C. W., … Poon, L. L. M. (2020). Stability of SARS-CoV-2 in different environmental conditions. In *The Lancet Microbe* (Vol. 1). China.

Ciplak, N. (2013). *A System Dynamics Approach for the Determination of Adverse Health Impacts of Healthcare Waste Incinerators and Landfill Sites on Employees*. *2*(2), 7–28.

Ciplak, N., & Barton, J. R. (2012). A system dynamics approach for healthcare waste management: A case study in Istanbul Metropolitan City, Turkey. *Waste Management and Research*, *30*(6), 576–586.

Clarissa, J., Halim, S., & Yahya, B. N. (2021). *Evaluasi Strategi kebijakan untuk Pandemi covid-19 di kota Surabaya dengan menggunakan simulasi sistem dinamik vensim Ventana*. Petra Christian University.

Eleyan, D., Al-khatib, I. A., & Garfield, J. (2013). System dynamics model for hospital waste characterization and generation in developing countries. *Waste Management & Research*, *31*(10), 986–995.

IESA. (2020). *Hasil Survey Jumlah Limbah Medis Era Covid-19*. Retrieved from https://www.iesa.or.id/artikel/hasil-survey-jumlah-limbah-medis-era-covid-19/

Ilyas, S., Ranjan, R., & Kim, H. (2020). Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *Science of the Total Environment*, *749*, 141652.

Le, A. B., Hoboy, S., Germain, A., Miller, H., Ms, R. T., Herstein, J. J., … Lowe, J. J. (2018). American Journal of Infection Control Major Article A pilot survey of the U . S . medical waste industry to determine training needs for safely handling highly infectious waste. *AJIC: American Journal of Infection Control*, *46*(2), 133–138.

Makajic-Nikolic, D., Petrovic, N., Belic, A., Rokvic, M., Radakovic, J. A., & Tubic, V. (2016). The fault tree analysis of infectious medical waste management. *Journal of Cleaner Production*, *113*, 365–373.

Morecroft, J. D. W. (2015). *STRATEGIC MODELLING and BUSINESS DYNAMICS* (2nd ed.). United Kingdom: John Wiley & Sons.

Nzeadibe, T. C., & Ejike-Alieji, A. U. P. (2020). Solid waste management during Covid-19 outbreak: policy gaps and prospects for inclusive waste governance in Nigeria. *Local Environment*, Vol. 25, pp. 527–535. Taylor & Francis.

Onoda, H. (2020). Smart approaches to waste management for post-COVID-19 smart cities in Japan. *IET Smart Cities*, *2*(2), 89–94.

Ranjan, M. R., Tripathi, A., & Sharma, G. (2020). Medical Waste Generation during COVID-19 (SARS-CoV-2) Outbreak and Its Management : An Indian Perspective. *Asian Journal of Environment & Ecology*, *13*(1), 10–15.

Rothan, H. A., & Byrareddy, S. N. (2020). The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *Journal of Autoimmunity*, *xxx(xxxx)x*(February), 102433.

Shih, L.-H., & Lin, Y.-T. (1999). Optimal Routing for Infectious Waste Collection. *Journal of Environmental Engineering*, *125*(5), 479–484.

Singh, N., Tang, Y., Zhang, Z., & Zheng, C. (2020). COVID-19 waste management: Effective and successful measures in Wuhan, China. *Resources, Conservation and Recycling*, Vol. 163. Elsevier B.V.

Sterman, J. D. (2000). *Business Dynamic-system thinking and modeling for a complex world*. irwin/McGraw-Hill.

Susilawati, S., Falefi, R., & Purwoko, A. (2020). Impact of COVID-19's Outbreak on the Economy of Indonesia. *Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences*, *3*(2), 1147–1156. https://doi.org/10.33258/birci.v3i2.954

Sy, C., Ching, P. M., Lois, J., Juan, S., Bernardo, E., Miguel, A., … Mutuc, J. E. (2021). Systems Dynamics Modeling of Outbreak Influenza for Strategic Policy Development : a Simulation-Based Analysis of the COVID-19 Case. *Process Integration and Optimization for Sustainability*.

Violetta, P. T. (2020, November 13). KLHK catat peningkatan 30-50 persen limbah medis saat pandemi. *Antaranews*.

Voudrias, E. A. (2016). Technology selection for infectious medical waste treatment using the analytic hierarchy process. *Journal of the Air & Waste Management Association*, *66*(7), 663–672.

Voudrias, E., & Graikos, A. (2014). Infectious Medical Waste Management System at the Regional Level. *Journal of Hazardous, Toxic, and Radioactive Waste*, *18*(4), 04014020.

Wang, J., Shen, J., Ye, D., Yan, X., Zhang, Y., Yang, W., … Pan, L. (2020). Disinfection technology of hospital wastes and wastewater : Suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) outbreak in China. *Environmental Pollution*, *262*, 114665.

Wichapa, N., & Khokhajaikiat, P. (2017). *Using the Hybrid Fuzzy Goal Programming Model and Hybrid Genetic Algorithm to Solve a Multi-Objective Location Routing Problem for Infectious Waste Disposal*. *10*(5), 853–886.

Worldometer. (2020). COVID-19 CORONAVIRUS OUTBREAK. Retrieved July 21, 2020, from Worldmeter.com website: https://www.worldometers.info/coronavirus/

Yu, H., Sun, X., Solvang, W. D., & Zhao, X. (2020). Reverse Logistics Network Design for Effective Management of Medical Waste in Epidemic Outbreak: Insights from the Coronavirus Disease 2019 (COVID-19) in Wuhan. *International Journal of Environment Research and Public Health*, *17*, 2–25.

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Biographies

Agus Mulyadi is a Master's student in Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember, Indonesia. He has a bachelor's degree in Industrial Engineering, obtained in Universitas Muhammadiyah Riau, Indonesia.

Niniet Indah Arvitrida is a Lecturer in Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember (ITS) Indonesia. Before taking on a Ph.D. in Simulation at Loughborough University, UK, she was working in academia and being a professional trainer in production management, material management, and logistics and supply chain management for corporates and small and medium enterprises in Indonesia. She also has a Master of Engineering in Supply Chain Management and Bachelor of Engineering in Industrial Engineering, both obtained with honors (cum laude) in ITS, Indonesia.