Integrated Simulation Model of Agent-based Modelling and Discrete Event Simulation

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ABSTRACT

One technique for resolving problems in the real world is simulation. A single simulation method might not be adequate to solve the problem due to its complexity. In reality, the current complicated problems are frequently unreachable by a single simulation method, requiring the integration of simulation methods. For instance, Discrete-Event Simulation (DES) is appropriate to model processes while entities are passive, whereas Agent-Based Modelling (ABM) is capable to model autonomous entities. Therefore, this study aims to develop an integrated simulation model of DES and ABM and demonstrate its application. The integrated ABM and DES was used to model flood evacuation in Kampung Melayu sub-district, Jakarta. While DES is a process-oriented method that can describe the current evacuation process, ABM is a bottom-up approach method that can accommodate for the heterogeneity of the population's evacuation decision. The developed model integrates the decision-making process for evacuation with the evacuation process on a single platform. This model simulates that the time needed in evacuation process is 122 minutes, the number of residents who need to be evacuated is 240 residents in which 62 residents need to be evacuated by inflatable boat. Moreover, the simulation model reports the number of residents at the shelter over time, and the time required for each resident to evacuate, which has the average time of 33.8 minutes.

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1. Introduction

Modelling is a technique for resolving problems in the real world. It is suitable when conducting experiments or prototyping in the real world is not possible. There are two ways in modelling, an analytical method and a simulation method. An analytical modelling result functionally depends on the input (a number of parameters). However, an analytical solution does not always exist, sometimes it is very hard to find. Therefore, simulation modelling may be applied (Borshchev and Filippov, 2004). A simulation modelling is better to use when the problem is complex and uncertain. According to Shannon (1992), simulation is a process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behaviour of the system and/or evaluating various strategies for the operation of the system. Based on the definition, a simulation can be used to describe the system behaviour, build hypotheses related to the system behaviour, and predict subsequent behaviour resulting from changes in the system.

Simulation has three different methods, Discrete Event Simulation (DES), System Dynamics (SD), and Agent-based Modelling (ABM). The differences of these three methods have been explained by Sopha and Sakti (2020). Discrete-Event Simulation (DES) method uses a process-centric approach in which the entity has no self-determination (passive). This method can model from micro to meso-level of abstraction with the maximum detail level. System Dynamics (SD) takes aggregate modelling method (top-down approach). The entities in this model will be assumed as homogeneous. System will be modelled in a macro level of abstraction with a few details. Agent-based Modelling (ABM) applies a bottom-up approach. In this method, the entities are heterogeneous and have autonomy (active). ABM will model the system in all levels of abstraction, i.e., micro, meso, and macro. The differences between these methods bring advantages and disadvantages to each method.

Different problems may need different simulation methods depending on the objective, the available data, and the nature of the real system. However, the problem frequently cannot completely conform to one modelling method (Borshchev, 2013). As the result of simulation method limitations, representing the real world phenomena through only single simulation method may cause the model is too simple for the intended purpose or too much detail and thus hard to understand. A combination of different simulation methods is able to answer each method's limitation. An integrated simulation model, also known as multi-method simulation approach, is taken advantages of the potentially of each simulation method (Balaban and Hester, 2013). Therefore, the appropriate level of abstraction can be chosen and vary the model efficiently. Although studies related to integrated simulation models have been conducted in recent years, they remain relatively few. It appears that the need for the integrated simulation model will increase in the future because problems are becoming increasingly complex and cannot be adequately addressed by a single simulation method.

This research aims to develop a simulation model integrating Agent-based Modelling (ABM) and Discrete Event Simulation (DES) and to demonstrate its application. The developed model addressed a flood evacuation in Kampung Melayu sub-district, Jakarta Timur. The integrated model modelled evacuation decision making by heterogenous residents and evacuation processes requiring resources such as trucks, volunteers, and boats. Hence, the paper has two contributions. First, it contributes to the advancement of knowledge through the developed integrated simulation model. Second, it provides insights for disaster management agency for efficient and effective evacuations.

To meet the objectives, the paper is structured into six parts. The first part discusses the motivations, which is followed by theoretical framework in Section 2. Section 3 presents the development of the integrated simulation model, whereas Section 4 discusses a studied case. Section 5 presents findings, which is then concluded in Section 6.

2. Theoretical Background

Various studies related to simulation have been conducted. Three common methods used in the studies are Discrete-Event Simulation (DES), System Dynamics (SD), and Agent-based Modelling (ABM). In fact, many problems often cannot completely conform to one modelling method (Borshchev, 2013). Therefore, a multi-method study was carried out.

Literature related to integrated simulation models, which combine two or more of the aforementioned simulation approaches, can be found in computer science and engineering journals. The main application areas are manufacturing, supply chain management, and healthcare (Brailsford *et al*., 2019). Rabelo *et al*. (2003) conducted a study on manufacturing enterprise simulations. The study focused on production decisions and their relation to business decision within supply chain enterprise, using integration of the DES and SD method. The DES method used to capture material flow, information flow, jobs flow, resource utilization, and short-term impacts of time delays, while the SD method captured the long-term effects of the impact of local production decisions on the entire enterprise. The combination of these two methods allows for simulation at different hierarchical levels within the enterprise.

Integrated simulation models in manufacturing were also conducted by Sadeghi *et al*. (2016) and Nasehi and Colledani (2018). Sadeghi *et al*. (2016) developed a model of complex semiconductor manufacturing process which combined the DES and ABM methods. ABM is a suitable method for modelling manufacturing system that have a large scale and consist of several types of tool group agents. Meanwhile, the DES method was used to describe the process inside tool group agents, where the processing times differ according to the lots type. Nasehi and Colledani (2018) conducted an integrated model of enterprise strategy related to the remanufacturing process. This study focused on evaluating the interaction effect between customer behaviour and company strategy on the economic feasibility of the remanufacturing process. The SD method was used to analyse the enterprise strategies and long-term policies and their effects on production. On the other hand, the ABM method was used to describe the differences in customer behaviour.

Healthcare is one of the main application areas that is often issued the integrated simulation model studies. Chalal and Eldabi (2008) conducted a study related to strategic and operational level decision making in the healthcare sector. A combination of DES and SD methods allowed for the modelling the stochastic, continuous, and qualitative aspects of the healthcare system. Additionally, this combination is proposed for effective decision making and allows for the evaluation of the impact of decisions from both strategic as well as operational perspective.

Aringhieri (2010) conducted a study related to the integration of ABM and DES method in emergency medical service management. The DES method was used to model the workflows in emergency medical service management, while the ABM method was used to model the interaction between the ambulance and its environment. Geographic Information System (GIS) was used to model the movement of the ambulance, thus enabling it to describe the actual mileage. Barnes *et al*. (2011) conducted a multi-method simulation using integration of SD and ABM method. This study investigated the impact of transferring patients between different healthcare facilities. Each healthcare facility was modelled as an agent which has a unique state consisting of the proportion of patients. The ABM method enables the comparison of infection-control strategies at one or more healthcare facilities that may be at risk due to an influx of received transferred infected patients. On the other hand, transitions between patient infection states are modelled using the SD method. Integration of SD and ABM methods allows for understanding the impact of the heterogeneity and stochasticity of the patient transfer configuration.

Supply chain management is frequently reviewed on multi-method simulation studies. In this area, a multi-method simulation is usually used to combine the issues at both strategic level and operational level. The SD method is used to modelling strategic level issues, while the DES or ABM method is used to modelling operational level issues. Several related studies have been conducted by Jovanoski *et al*. (2013), Venkateswaran and Son (2005), Mittal and Krejci (2015), and Rabelo *et al*. (2014). Jovanoski *et al*. (2013) and Rabelo *et al*. (2014) integrated DES and SD methods to model at both the operational and strategic levels. Jovanoski *et al*. (2013) used the SD method to model the sales workforce, while the DES method was used to model production. Venkateswaran and Son (2005) studied about production planning using an integrated model of DES and SD. The SD method was used for enterprise-level planning, while DES was used for shop-level scheduling. Meanwhile, Mittal and Krejci (2015) built a simulation of logistics operations in a regional food hub using a combination of ABM and DES methods. This model observed the scheduling behaviour of producers and explored the effectiveness of implementing incentives to encourage producers to schedule their deliveries in advance.

Although the literature related to integrated simulation model has increased in recent years, it is still relatively few. While in the future the problems will be more complex thus the integrated simulation model will be increasingly needed. Most of the integrated simulation models that have been built are integration between DES and SD (Brailsford *et al*., 2019). In a study conducted by Brailsford *et al*. (2019), the use of the integration of the ABM and DES methods in the literature is still few compared to the integration of other methods, such as DES with SD and ABM with SD. Therefore, this study will build a multi-method simulation model by integrating ABM and DES methods.

One area where the integration of ABM and DES can be applied is supply chain management. This study will focus on humanitarian logistics, specifically in flood evacuation process. While various study related to simulation of evacuation processes have been conducted, the use of a multi-method approach is still few. Studies of evacuation process using integrated ABM and DES method have been conducted by Zhang *et al*. (2014) and Na and Banerjee (2019). Zhang *et al*. (2014) developed a modelling framework for transportation evacuation, and experimental result showed that implementing the integration of ABM and DES methods was significantly more efficient than using a pure ABM method. Meanwhile Na and Banerjee (2019) developed a modelling framework for natural disaster evacuation. Furthermore, Sopha *et al*. (2021) deployed the integration of ABM dan DES to model evacuation of mount eruption in order to examine the effectiveness and efficiency of evacuation plan by incorporating sustainability indicators. The integration of ABM and DES method in this study is intended to accommodate the heterogeneity of individual behaviour in decision making and to model the evacuation process with a process-oriented approach for flood evacuation which uses two types of vehicles, i.e., trucks and boats.

3. Methodological Approach

The methodology section should describe in detail the approaches/techniques used in the study so it can be replicated and developed by other researchers. Unless there are well-established methods, it can be briefly explained. If the study uses equipment or instruments, it is also necessary to mention the specifications. The present study integrated Agent-Based Modelling and Discrete-Event Simulation in one platform. AnyLogic 8.6 Personal Learning Edition software was used to develop the integrated model. To develop the integrated model, the research followed a methodology consisting of five stages.

Literature review was conducted to understand the principles and basic assumptions of ABM and DES and explore the potential integration between both. In addition, the literature review was also conducted to understand the existing model of evacuation. The literature review was conducted by searching relevant literatures from reputable and reliable sources journals and conference proceedings from reputable databases. The second stage is system characterization. At this stage, characteristics identification of the studied case was carried out through observations, secondary data sources Regional Disaster Management Agency (BPBD) and provincial government of DKI Jakarta. This study will focus on the flood evacuation process in Jakarta, specifically in Kampung Melayu sub-district. The simulation will model an evacuation process based on a contingency plan designated through Peraturan Gubernur DKI Jakarta. This stage also addresses assumptions and boundaries of the model. Based on the system characterization, important variables were also collected and used to develop instruments for data collection. The required data related to the Jakarta floods include the distribution of Jakarta's population, the flood-affected locations, the location of evacuation shelters, and the capacity and speed of the vehicles used for evacuation. Those data will be obtained from Jakarta government portal and Badan Pusat Statistik (Central Statistics Bureau) portal. In addition, latitude and longitude of the location are required. These data obtained from Google Maps will be used as an input to the GIS Maps in the software. The third stage regards with building conceptual model. The conceptual model was constructed based on empirical data collection. The collected data were flood-related data, such as the affected locations, the evacuation barracks locations, as well as, the evacuation vehicle specifications, and population-related data such as the socio-demographic distribution, and the evacuation behaviour. The conceptual model specifies the logic and attributes of each individual in the population and evacuation processes. Once the conceptual model was constructed, it went to validation processes. The model validation was conducted through focus group discussion with experts, representatives from national agency for disaster management, local government, and non-governmental organization. The fourth stage is model implementation using an integrated Agent-Based Modelling and Discrete Event Simulation in AnyLogic software, followed by model verification which was conducted through debugging walkthrough. Data for model parameterization was also collected at this stage. Results of the simulation model was contrasted with the general evacuation pattern because the empirical data of evacuation is not available, indicating that the developed model has gone model validation. The last stage discusses the results and insights gained from the simulation results. It is worthy to note that the scope of the present study is to demonstrate the application of the integrated simulation approaches of ABM and DES, which does not necessarily represent the accurate model of the studied case.

4. A Studied Case: Flood Evacuation in Kampung Melayu, Jakarta

This study was based on Jakarta flood evacuation process, specifically in Kampung Melayu sub-district. DKI Jakarta province government has made a contingency plan for controlling Jakarta flood disaster. As the capital city of Indonesia, as well as the centre of economic activities, industry, trade, education, and others, indeed, Jakarta has become a major destination for many individuals to earn a living. The population growth rate reached 1,39% per year over the period 2000-2010 (BPS DKI Jakarta, 2010). This made Jakarta the most densely populated city in Indonesia as it is expected to reach 30 million population by 2030. Jakarta is one of the cities which is susceptible to flooding (Yoo *et al*., 2014). Floods in Jakarta is not a new issue, there is always a flood every time it rains. Thirteen rivers flow into the Jakarta Bay caused DKI Jakarta have a high vulnerability to flood. Huge flood occurs annually in Jakarta and its neighbouring areas. Jakarta has experienced major flooding since 1621, 1654, 1876, 1976, 1977, 1984, and 1989 (Marfai, 2013).

The flood potential in Jakarta is impacted by three main aspects. First, flood caused by high local rainfall which create overflows in rivers and drainage canals. Second, flood caused by high rainfall in upstream areas (Depok, Bogor, Puncak and Cianjur). Third, flood caused by rising sea levels (rob) which prevent water from dissipating into the sea. A five-year periodic flood in 2002, which covered about one-fifth of Jakarta's total area, caused 5,4 trillion rupiahs worth of damages. Similarly, flood in 2007 caused 5,2 trillion rupiahs worth of damages (Bappenas, 2007). The severe flood due to heavy monsoon rains in January 2013 resulted 40 deaths, 45.000 evacuees, and substantial economic damage (Kure *et al*., 2014).

There are several flood-prone areas in DKI Jakarta. These shown in Figure 1. Kampung Melayu is one of the sub-districts which has a high level of vulnerability to flood. Kampung Melayu sub-district is located on the Ciliwung riverbanks. Although flood management plan that has been conducted since 2007 can reduce the risk, the floods in 2013, 2014, and 2015 show that flood is still a significant annual problem and requires further mitigation (BPBD DKI Jakarta, 2014 and BPBD DKI Jakarta, 2015). Kampung Melayu is sub-district located in Jatinegara district with a population of 22,969 people (Yuan and Tan, 2011). The sub-district is located adjacent to the Ciliwung river, most residents live in a high-risk settlement near Ciliwung riverbanks. Kampung Melayu was one of the most floods affected areas in January 2014, which is home to 15% of the total population in DKI Jakarta affected by flood (BPBD DKI Jakarta, 2014). The water level reached 2-5 meters height which forced evacuation of some residents.

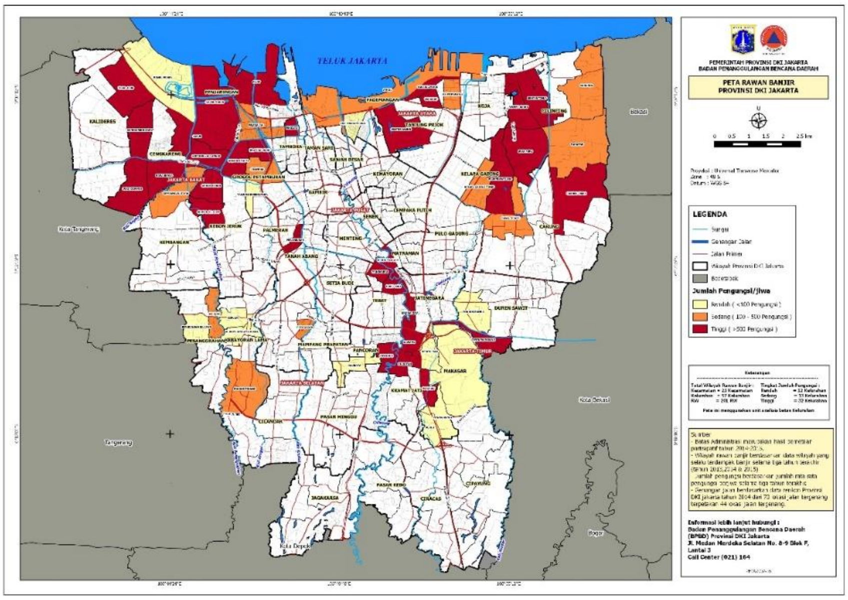


Figure 1. Flood-prone areas of DKI Jakarta Province (BPBD DKI Jakarta, 2015)

Badan Penanggulangan Bencana Daerah Provinsi DKI Jakarta designed Jakarta flood management in a contingency plan document. There are three flood scenarios based on the different of water level, i.e., Siaga III, Siaga II, and Siaga II. 16 sub-districts are affected in Siaga III scenario, 25 sub-districts are affected in Siaga II, while 49 sub-districts are affected in Siaga I. Kampung Melayu is one the sub-district affected in all scenarios, Siaga III, Siaga II, and Siaga I. The threshold for flood status in Ciliwing river is the water level at Katulampa sluice. After receiving a warning regarding flood status, some residents decided to evacuate by walking to the assembly point while others chose to stay in their homes until the flood level is high.

Residents who decided to evacuate will walk to the assembly point through shortest route. Walking speed during evacuation is between 1.2 m/s to 1.8 m/s (Shi *et al*, 2009). If it classified based on population groups, children will walk at 1.08 m/s speed, adults will walk at 1.27 m/s speed, and elderly will walk at 1.04 m/s speed. Shi *et al*., (2009) also consider the crowded of the road which is 0.43 person/m2 or it can be interpreted that everyone square meter road can be passed by up to two walking people. After walking to the assembly point, refugees will be evacuated by volunteers to designated shelter using military trucks with a capacity of 30 people and a speed of 70 km/hour. Some residents may choose to stay in their homes until the flood level is higher. In that case, they will be evacuated to the assembly point by volunteers using inflatable boats. Once at the assembly point, refugees will be evacuated to the shelter using military trucks.

5. An Integrated Simulation Model of ABM and DES – Flood Evacuation in Kampung Melayu, Jakarta

5.1 Conceptual model

The conceptual model consists of two parts, i.e., evacuation decision-making and evacuation processes as shown in Figure 2 and Figure 3 respectively. There are six types of agents in the model, which are resident, military truck, inflatable boat, vehicle base location, assembly point, and shelter. Attributes of each agent are shown in Table 1. Residents will be divided into two categories based on their agent attributes, which are immediate-evacuation agent and late-evacuation agent. The evacuation decision attribute is determined based on age, gender, and type of house. An agent who decides to evacuate immediately is either female, has a one-floor house type, or is either less than 18 years old or more than 60 years old. Meanwhile, late-evacuation agents are those who do not immediate evacuate. Resident who is immediate-evacuation agent will walk to the assembly point when the flood occurs, while resident who is late-evacuation agent will stay at home and wait for volunteer to pick them up using inflatable boats and take them to the assembly point. Figure 2 also shows the interaction among different types of the agents. The agents' decision making and their interaction is implemented in ABM.

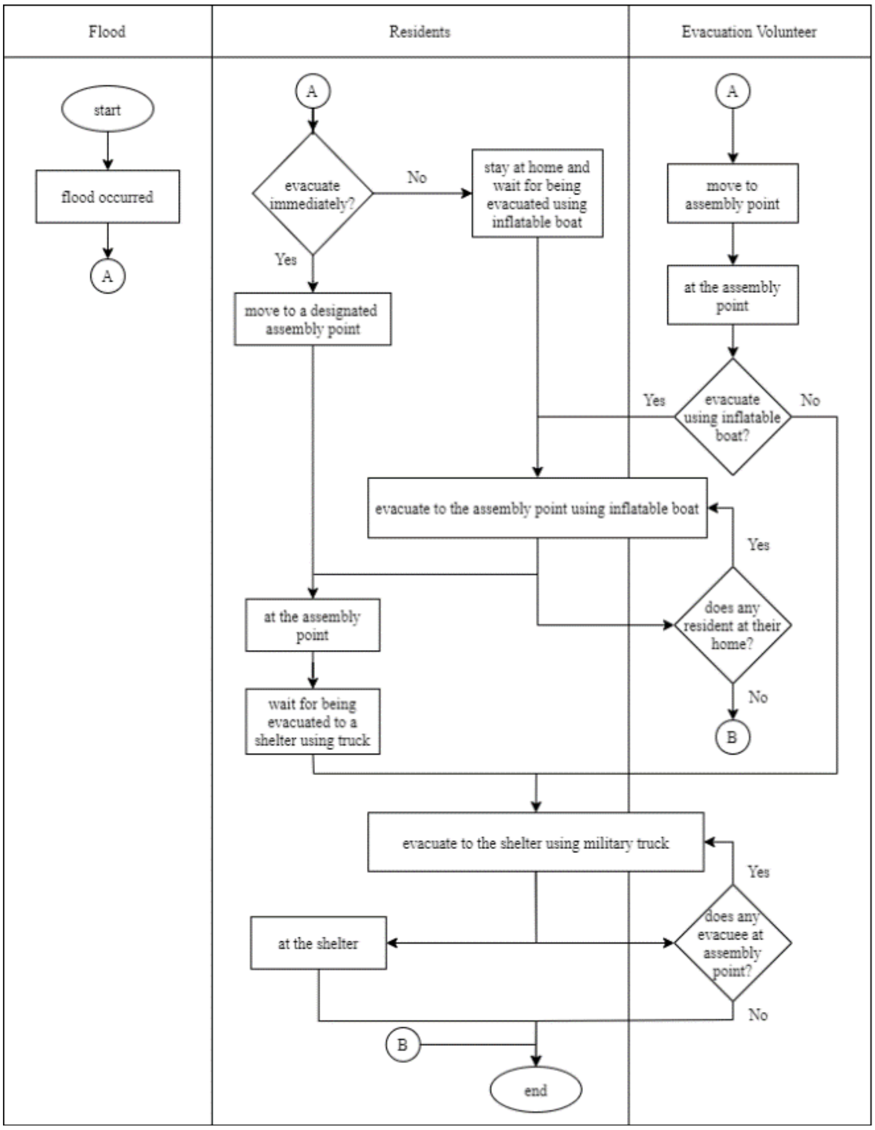


Figure 2. Decision making of agents and their interactions

Table 1. Agent attributes

Agent	Attribute	Description
Resident	Age	1-80 years old
	Gender	1. Male
		2. Female
	House type	1. One-floor house
		2. Two-floor house

Agent	Attribute	Description
	Evacuation decision	1. Evacuate immediately 2. Late evacuate
	Location	Agent is located in Kampung Melayu sub-district
	Assembly point	There is a designated assembly point for resident in one sub-district
	Shelter	There is a designated shelter for resident in one sub-district
	Velocity	The walking speed is 1.27 m/s
	Total evacuation time	The total evacuation time is the time taken by residents to go to the assembly point, wait, and evacuated to the shelter
Military truck	Location	The truck base location is in Rumah Zakat
	Capacity	A truck has capacity for 30 people
	Velocity	The truck speed is 70 km/h
Inflatable boat	Location	The inflatable boat location is in Rumah Zakat
	Velocity	The inflatable boat is 9.26 m/s
Vehicle base location	Location	Vehicle base location is the initial location of military truck and inflatable boat
Assembly point	Location	There is one designated assembly point in Kampung Melayu sub-district
Shelter	Location	The shelter location is in Masjid Itihadul Ikhwan

Figure 3 shows the evacuation processes involving the resident agents, military truck agents, and inflatable boat agents. The evacuation process depicted as Activity Cycle Diagram was implemented in DES. Three entities are defined for the DES model, which are resident, military truck, and inflatable boat.

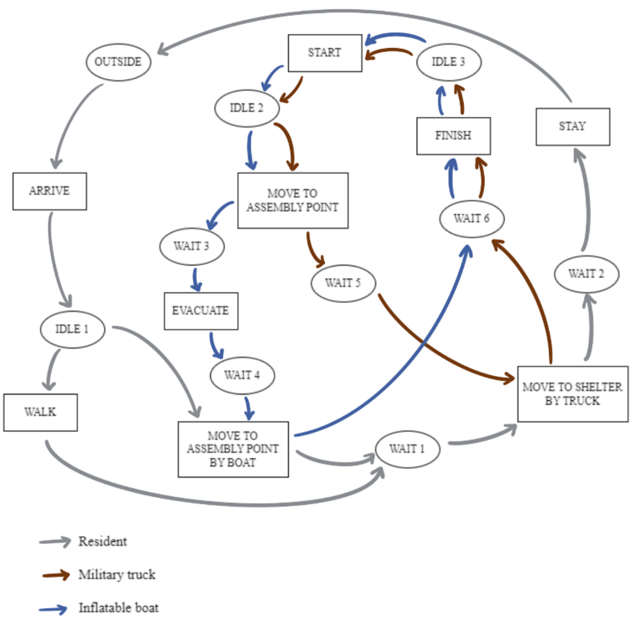


Figure 3. Evacuation process

Resident is temporary entity, while military truck and inflatable boat are permanent entities. The flow of entities is shown in Figure 3. Residents enter the system, and some of them will walk to the assembly point while others will wait for volunteer to evacuate them using inflatable boats. In the other hand, volunteer with military truck and inflatable boat will move to assembly point. Then volunteer with inflatable boat will move to resident's house and evacuate the resident to assembly point. While volunteer with military truck will evacuate the resident from assembly point to shelter. After arrived at the shelter, residents will wait and then leave the system.

5.2 Simulation model

There are several assumptions and constraints in the model. First, the population modelled is only the population affected by the flood. Second, the resident location is chosen randomly within the scope of Kampung Melayu sub-district. Third, it is assumed that the speed of resident agent is the same where adult walking speed is taken. Fourth, it is assumed that one inflatable boat is only used to pick up one resident agent. Lastly, the location of the assembly point is assumed to be at the edge between the location of the immediate-evacuation agents and the late-evacuation agents.

The integration of ABM and DES is the approach used to implement the integrated simulation model. ABM is used to represent the heterogeneity of agents, including the evacuation decision behaviour of residents, which can be divided into immediate evacuation and late evacuation. Meanwhile, DES is used to simulate the evacuation process by inflatable boat and military truck. The framework of multi-method model can be seen in Figure 4.

The developed integrated ABM-DES model was built using the architecture of *processes inside agent*. Resident agents were residents of Kampung Melayu who carried out the evacuation process, as many as 240 agents. Resident agents have several states, depicted in Figure 4, as the following. *AgeIdentification* state identifies agent attributes. Resident agents with age parameters less than 18 and over 65 will move to the *ImmediateEvacuationAgent* state, while other resident agents will move to the *GenderIdentification* state. This state identifies the gender attribute of resident agents. The gender attribute in the model is determined based on the resident's gender data. Furthermore, resident agents with female gender parameters will move to the *ImmediateEvacuationAgent* state, while other resident agents will move to the *HomeIdentification* state. *HomeIdentification* stage identifies the type of house belonging to a resident agent. The house type attribute is determined based on statistical data from the Provincial Government of DKI Jakarta where as much as 19.69% have a floor area of more than 100 m^2 which is assumed to be a one-floor house. Resident agents with a one-floor house type parameter will move to the *ImmediateEvacuationAgent* state, while other resident agents will move to the *LateEvacuationAgent* state. Resident agents with *ImmediateEvacuationAgent* state perform immediately evacuation and resident agents with *LateEvacuationAgent* state performs late evacuation. *AtHome_IEA* state represents the resident agents who stay at home and will perform immediate evacuation. The resident agents performing immediate evacuation would have *MoveToAssemblyPoint* state when flood occurs. In this state the resident agent with the attribute of immediate evacuation goes to the gathering point on foot. The resident agent will walk at a speed of 1.27 m/s. Resident agents will move following the route formed by the OSM server from AnyLogic. When the resident agent has arrived at the gathering point, it will move to the *AtAssemblyPoint* state. This state is a condition where resident agents wait for evacuation volunteers who will evacuate resident agents to the evacuation barracks using military trucks. In this state the resident agent will move to the DES method process flow. When the resident agent arrives at the evacuation barracks, the resident agent will send a message and move to the *AtShelter* state. This state describes the condition of resident agents who have arrived at the evacuation barracks. Furthermore, the resident agent will stay in the barracks to evacuate. *AtHome_LEA* state represents the resident agents stays at home and do late evacuation. These resident agents will move to the *WaitForEvacuation* state if a flood occurs. Once the volunteer agents arrive to evacuate them, the resident agents’ state is changed to *EvacuateToAssemblyPoint* state, representing that rubber boat agents have arrived at the location of the resident agents. When the resident agent has arrived at the collecting point, the resident agent will move to the *AtAssemblyPoint* state.

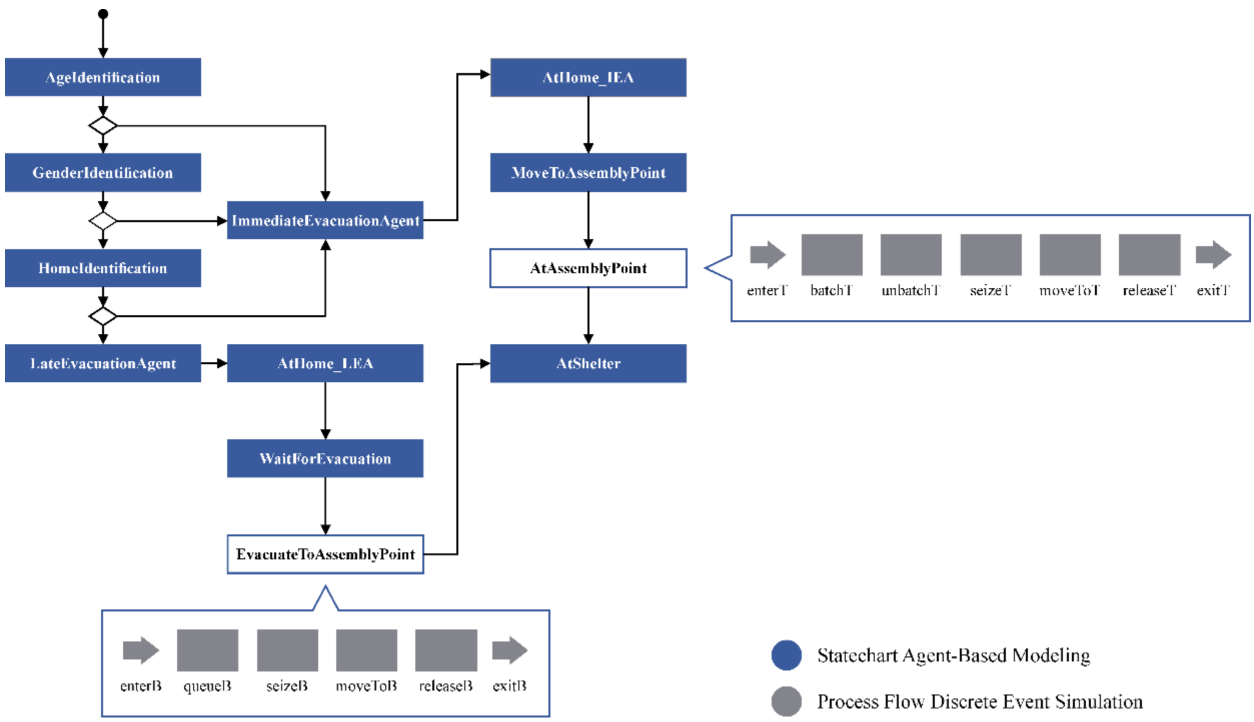


Figure 4. Framework of the integrated ABM and DES simulation model

The simulation model has been built based on the conceptual model and has been verified and validated. The simulation can represent the number of residents successfully evacuated to the shelter per minute. In addition, the simulation can also capture the total evacuation time needed for each resident. The output chart of the number of residents successfully evacuated to the shelter can be seen in Figure 4. Based on the simulation results, there are 62 residents who need to be evacuated using inflatable boat and the evacuation process of residents in Kampung Melayu village takes 122 minutes. Meanwhile, the average time required for the evacuation process of each resident is 33.8 minutes. The quickest evacuation time for each resident is 8.5 minutes and the longest time is 121.3 minutes.

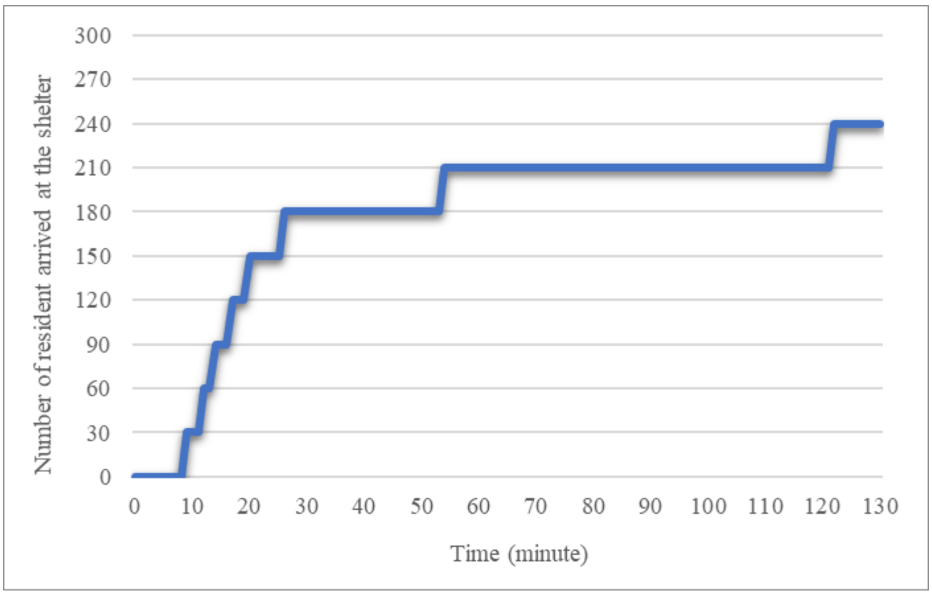


Figure 5. Total number of resident agents (evacuees) arrived at the shelters

5.3 Model validation

In this model, macro-empirical validation is carried out by comparing the graphical pattern of data on the number of successfully evacuated agents per time with similar research due to unavailability of empirical evacuation data. Because the integrated simulation model can be categorized as pattern-oriented modelling (POM), the model validation was conducted by contrasting the resulted pattern of the developed model with that of other evacuation studies. Table 2 presents the comparison of evacuation pattern between two models, indicating the rapid evacuation in early time and decreasing rate afterward.

Table 2. Comparison of evacuation pattern between the integrated approach and circular automata

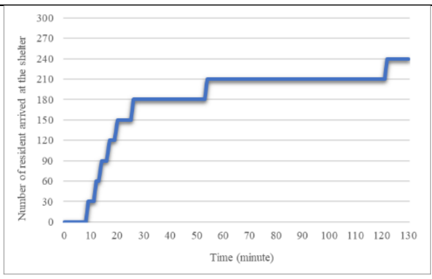
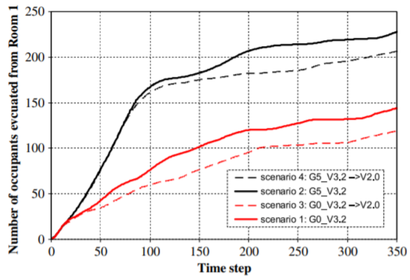
	This Simulation Result	Similar Simulation Results
Chart		
Simulation method	Agent-based Modeling and Discrete Event Simulation	Cellular Automata
Simulation focus	Flood disaster evacuation	Evacuation from a smoke-filled compartment
Reference	The present study	Yuan and Tan (2011)

Table 2 shows that the pattern resulted from the present study and that using cellular automata has similarity, indicating that the simulation output is validated. The simulation model can further be used to estimate evacuation time and observe number of arrived evacuees over time in each shelter.

6. Conclusion

As the problem becomes more complex, a new approach is necessary. The present research proposed an integrated simulation model to model evacuation in flood disaster. The developed model integrates the Agent-Based Modeling (ABM) and Discrete Event Simulation (DES) approaches. The ABM approach with a bottom-up approach was chosen because it can accommodate heterogeneity in the behaviour of the decision to evacuate residents, while the DES approach with a process-oriented approach is used to describe the existing evacuation process using inflatable boat and military truck. Flood evacuation in Kampung Melayu, Jakarta Timur, was taken as a studied case. The simulation model was parameterized with empirical data and was able to reproduce general pattern of evacuation, indicating the validity of the developed simulation model.

The simulation result shows that there are 240 needing to be evacuated whereas 62 residents need to be evacuated using inflatable boats. The total evacuation time is 122 minutes to evacuate all residents in Kampung Melayu, Jakarta. Each resident has an average evacuation time of 33.8 minutes. Because the developed simulation model only addresses one region, future research can extend the model to demonstrate the applicability of the model to other regions affected by floods. Another future research could focus on the refinement of the conceptual model and the integration framework.

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References

Aringhieri, R. (2010). An integrated DE and AB simulation model for EMS management, in: Health Care Management (WHCM). IEEE, 1–6.

Balaban, M. A., & Hester, P. (2013). Exploration of Purpose for Multi-method Simulation in the Context of Social Phenomena Representation, *Winter Simulation Conference*.

Bappenas (2007). *Laporan Perkiraan Kerusakan dan Kerugian Pasca Bencana Banjir Awal Februari 2007 di Wilayah Jabodetabek*, Technical Report, Kementerian Negara Perencanaan Pembangunan Nasional, Jakarta.

Barnes, S. L., Harris, A. D., Golden, B. L., Wasil, E. A., & Furuno, J. P. (2011). Contribution of Interfacility Patient Movement to Overall Methicillin-Resistant Staphylococcus aureus Prevalence Levels. *Infection Control & Hospital Epidemiology*, 32(11), 1073–1078.

Borshchev, A. (2013). Multi-method Modeling, *1st International Simulation Tools Conference and Expo 2013*, SIMEX 2013, 59-67.

Borshchev, A. & Filippov, A. (2004). From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools, *The 22nd International Conference of System Dynamics Society*.

BPBD DKI Jakarta (2014). *Rekapitulasi Kejadian Banjir 2014*, Jakarta: PUSDALOPS.

BPBD DKI Jakarta (2015). *Rekapitulasi Kejadian Banjir* 2015, Jakarta: PUSDALOPS.

BPS DKI Jakarta (2010). *Jakarta Dalam Angka 2010*, Jakarta: BPS DKI Jakarta.

Brailsford, S. C., Eldabi, T., Kunc, M., Mustafee, N., & Osorio, A. F. (2019). Hybrid Simulation Modelling in Operational Research: A State-of-the-art Review. *European Journal of Operational Research*, 278, 721-737.

Chahal, K., & Eldabi, T. (2008). Applicability of hybrid simulation to different modes of governance in UK healthcare, *Winter Simulation Conference*.

Jovanoski, B., Minovski, N., Lichtenegger, G., & Voessner, S. (2013). Managing strategy and production through hybrid simulation. *Industrial Management & Data Systems*, 113(8), 1110–1132.

Kure, S., Farid, M., Fukutani, Y., Muhari, A., Bricker, J. D., Udo, K., & Mano, A. (2014). Several Social Factors Contributing to Floods and Characteristics of the January 2013 Flood in Jakarta, Indonesia, *Journal of Japan Society of Civil Engineers Ser. G (Environmental Research)*, 70(5), 211-217.

Marfai, M. A. (2013). *Bencana Banjir Rob Studi Pendahuluan Banjir Pesisir Jakarta*, Graha Ilmu, Yogyakarta.

Mittal, A., & Krejci, C. C. (2015). A hybrid simulation model of inbound logistics operations in regional food supply systems. 2015 *Winter Simulation Conference* (WSC).

Na, H. S. and Banerjee, A. (2019). Agent-based discrete-event simulation model for no-notice natural disaster evacuation planning, *Computers and Industrial Engineering*, 129, 44–55.

Nassehi, A., & Colledani, M. (2018). A multi-method simulation approach for evaluating the effect of the interaction of customer behaviour and enterprise strategy on economic viability of remanufacturing, *CIRP Annals*, 67(1), 33–36.

Rabelo, L., Helal, M., Jones, A., Min, J., Son, Y. J., & Deshmukh, A. (2003). A Hybrid Approach to Manufacturing Enterprise Simulation, *Winter Simulation Conference*.

Rabelo, L., Sarmiento, A. T., Helal, M., & Jones, A. (2014). Supply chain and hybrid simulation in the hierarchical enterprise. *International Journal of Computer Integrated Manufacturing*, 28(5), 488–500.

Sadeghi, R., Dauzere-Pérès, S., & Yugma, C. (2016). A Multi-Method Simulation Modelling for Semiconductor Manufacturing. *IFAC-PapersOnLine*, 49(12), 727–732.

Shannon, R. E. (1992). Introduction to Simulation, *Proceedings of the 1992 Winter Simulation Conference.*

Shi, L., Xie, Q., Cheng, X., Chen, L., Zhou, Y., & Zhang, R. (2009). Developing a Database for Emergency Evacuation Model. *Building and Environment*, 44(8), 1724–1729.

Sopha, B. M. & Sakti, S. (2020) *Pemodelan dan Simulasi Berbasis Agen untuk Sistem Kompleks Sosio-Teknikal*, Yogyakarta: Gadjah Mada University Press.

Sopha, B. M., Triasari, A. I., & Cheah, L. (2021). Sustainable humanitarian operations: Multi-method simulation for large-scale evacuation. *Sustainability*, 13(13), 7488, 1-19.

Venkateswaran, J., & Son, Y.-J. (2005). Hybrid system dynamic—discrete event simulation-based architecture for hierarchical production planning. *International Journal of Production Research*, 43(20), 4397–4429.

Yoo,G., Kim, A. R., & Hadi, S. (2014). A methodology to assess environmental vulnerability in a coastal city: Application to Jakarta, Indonesia. *Ocean and Coastal Management*, 102, 169-177.

Yuan, W., & Tan, K. H. (2011). A model for simulation of crowd behaviour in the evacuation from a smoke-filled compartment. *Physica A: Statistical Mechanics and Its Applications*, 390(23-24), 4210–4218.

Zhang, B., Chan, W. K. V., & Ukkusuri, S. V. (2014). On the modelling of transportation evacuation: An agent-based discrete-event hybrid-space approach, *Journal of Simulation*, 8(4), 259–270.

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