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Designing a Discrete Simulation Model for Disaster Impact Area Mapping Routes Using a Combination of Land Vehicles and Drones

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ABSTRACT

Floods are Indonesia's most frequent natural disasters, necessitating disaster management activities. This involves mapping disaster-affected areas using a combination of land vehicles and drones. This study implements discrete simulations to address the numerous uncertain variables affecting the mapping process. Uncertainty such as setup time, traveling time of land vehicle & drones, and mapping time are considered. Existing simulation model for mapping disaster-affected areas with the same case study, reported that without the influence of those uncertain factors, the total mapping operation can be done within ping operation can be done within 24 hours utilizing 3 land vehicles and two drone routes at each stopping point of the land vehicles. However, utilizing the proposed model enables further detailed analysis on how uncertainty factors can affect the solution. The goals of the study is to find a shorter operation time using simulation and determine the most efficient resources needed to accomplish that. The result of this simulation reporting that the mapping operation can be shortened to be done in 16 hours however using more resources. The configuration applied in the simulation were able to minimize drone mapping time and determine the optimal number of land vehicles for the determined operation time.

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1. INTRODUCTION

Indonesia, an archipelago with thousands of islands, is frequently subjected to various natural disasters (Liperda et al., 2021). Among these, floods stand out as the most recurrent, causing significant damage to infrastructure property, and even leading to loss of life [1]. In the aftermath of such disasters, it becomes imperative to map the affected areas quickly and accurately. This mapping is not just for assessment but also to facilitate efficient relief and recovery operations.

Combining land vehicles and drones offers a promising solution to this challenge. While land vehicles can navigate through accessible areas, drones can provide aerial views, capturing data from regions that might be challenging for land vehicles to reach, especially in the immediate aftermath of a disaster when many routes might be blocked or submerged.

However, deploying these resources is not without challenges [2]. There's a need to optimise their use, ensuring that the affected areas are mapped comprehensively within a limited timeframe. This urgency stems from the fact that timely mapping can significantly influence the success of relief operations, potentially saving more lives and reducing the overall impact of the disaster.

This research aims to design a discrete simulation model to optimise the mapping process. The research hopes to provide a blueprint for real-world scenarios, ensuring that disaster-affected areas are mapped efficiently and relief operations are initiated based on accurate data.

This research is anchored on a specific case study of flood disaster in Bekasi that happen in January 2020. While the findings might be directly related to this event, the methodologies and insights could potentially be adapted to other similar disasters. The research also makes certain assumptions regarding the drone's operational capabilities, battery life, and setup conditions, which are crucial for the simulation model.

This paper begins with an "Introduction" that highlights the significance of mapping flood-affected areas in Indonesia using drones and land vehicles. The subsequent "Literature Review" explores existing studies on disaster management and drone usage. The "Methodology" section details the research approach and simulation model. Findings are presented and analyzed in the "Results and Discussion" segment. The paper concludes with key insights and suggestions in the "Conclusion and Recommendations" section.

2. LITERATURE REVIEW

Numerous research have substantially affected the evolution of catastrophe management systems. Zhou and Rose (2011) were among the earliest proponents of utilizing simulations to evaluate recovery activities, a technique that has now become a pillar of disaster management research. Luna et al. (2011) elaborated by concentrating on the complexities of disaster aid distribution and highlighting the need for more streamlined and effective mechanisms. In a related study, Smith & Johnson (2009) examined the psychological effects of timely relief on impacted communities and emphasized the significance of quick reaction mechanisms. Patel and Kumar (2013) highlighted the technology aspect by demonstrating the revolutionary potential of drones in surveying and appraising disaster-stricken areas. More recently, Gomez & Fernandez (2018) underlined the synergy between land vehicles and unmanned aerial vehicles, recommending a combined strategy for more complete coverage. Collectively, these studies demonstrate the complexity of disaster management and the ongoing attempts to develop and optimize systems.

Recent disaster management developments have highlighted the synergy between aerial and ground vehicles for post-event inspections. Redi et al. (2021) proposed a collaborative approach using both vehicle types, introducing two models, 2EVRPA and 2ECoVRP, to optimize routing in post-disaster scenarios, with the latter showing superior performance in the context of the Mount Merapi eruption. Building on this, another study by Redi and colleagues presented the 2ECOVRP-MOD model, which integrates drones and ground vehicles for efficient disaster mapping, particularly highlighting its effectiveness during the 2020 Bekasi floods. De Veluz et al. (2023) shifted the focus to pre-disaster planning, proposing a stochastic model for location-routing to streamline evacuation processes during typhoons in the Philippines. Liperda and team further delved into algorithmic solutions, comparing the efficacy of the Simulated Annealing algorithm against exact methods for the two-echelon vehicle routing problem. Lastly, a comprehensive study on relief mapping assessment underscored the importance of collaborative routing, emphasizing the need to minimize total mapping operation time, especially considering drone flight limitations.

3. METHODOLOGY

This research presents a comprehensive approach to mapping disaster-affected areas, specifically focusing on flood-impacted regions in Bekasi City as illustrated in Figure 1. Central to the study is the development of a conceptual model, which serves as a foundational framework illustrating the relationships between various variables and actors involved in the mapping process. To ensure the model's accuracy and relevance, extensive data collection was undertaken, capturing essential details like drone setup times, travel times for land vehicles, and specifics about the flood-affected areas. Once the data was integrated into the model, a simulation was run to predict and analyse the mapping outcomes. A two-step verification and validation process were employed to guarantee the model's fidelity to the real-world scenario. Verification ensured that the simulation model was a true representation of the conceptual model, while validation confirmed that the conceptual model accurately depicted the actual system being studied. The later paragraph explains in more detail the methodology being used in this study.

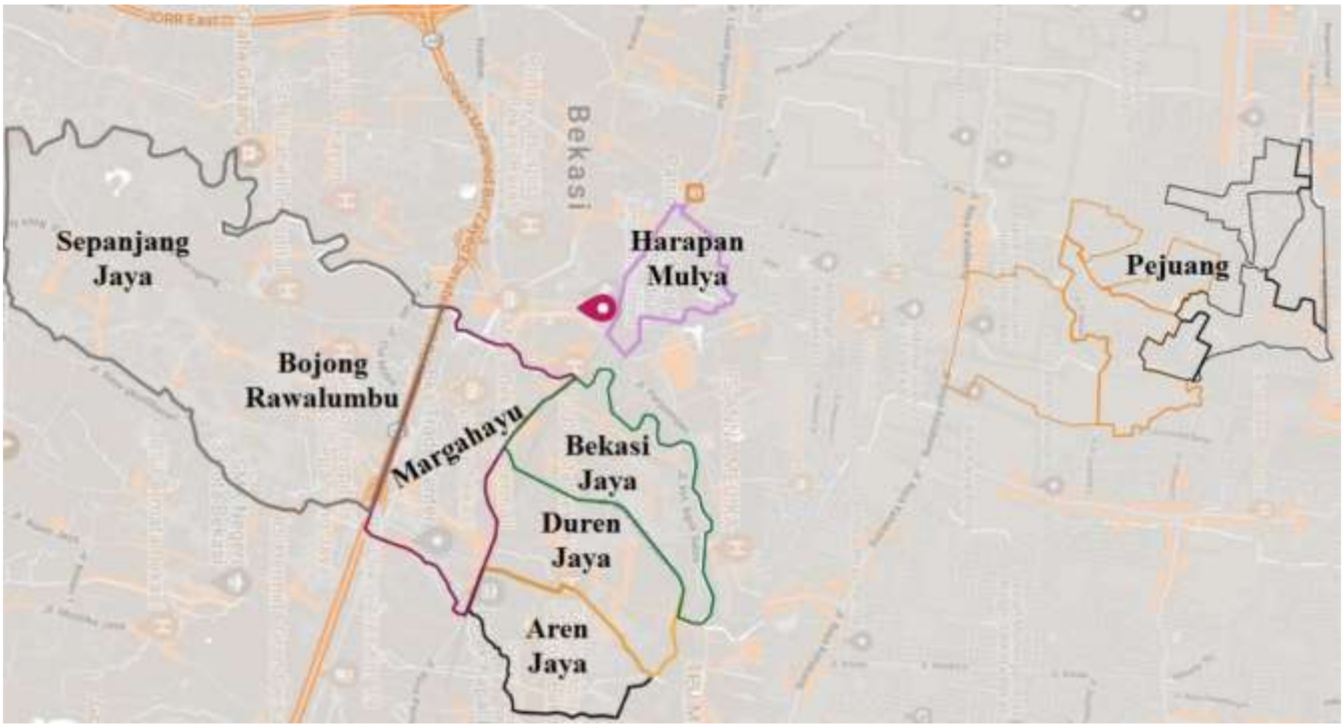
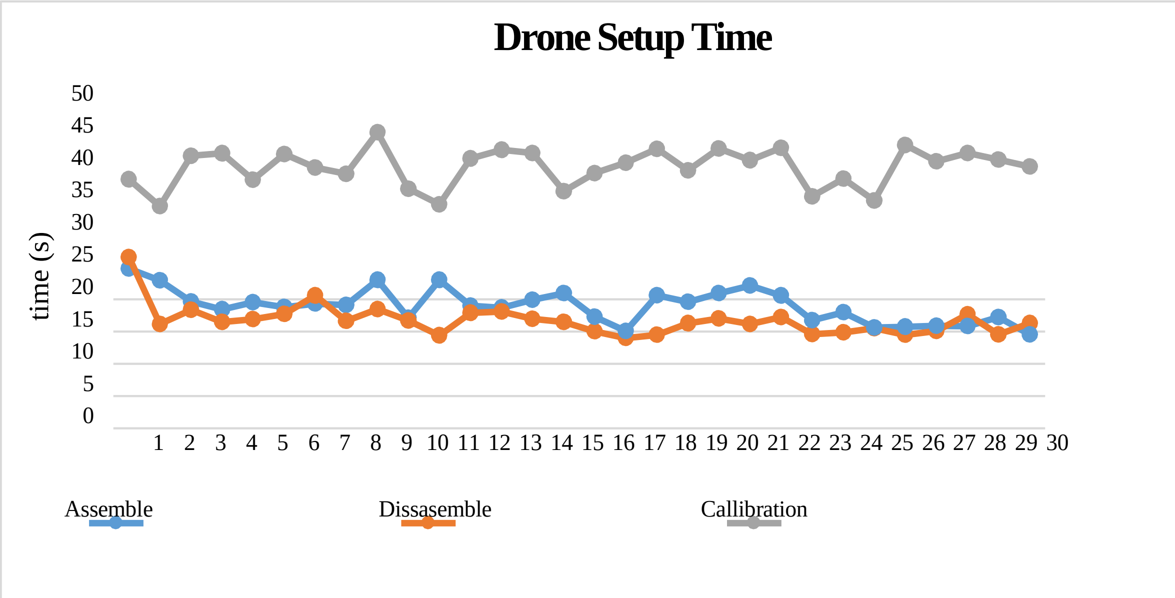
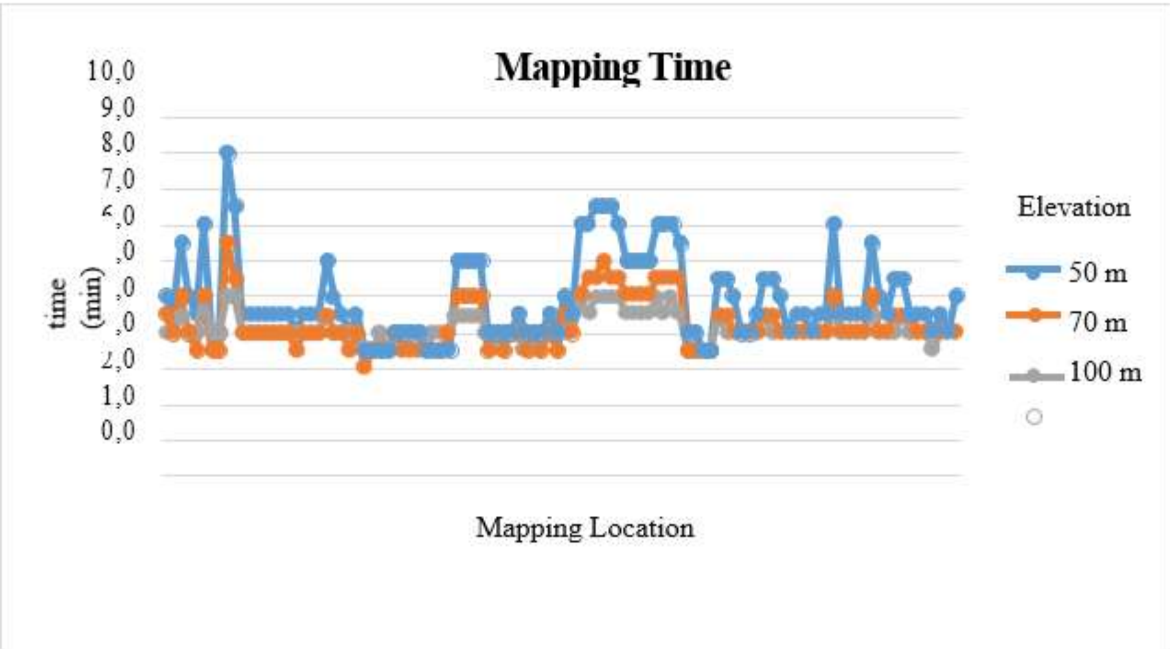


Figure 1. Illustration of focused area of the study: flood-impacted regions in Bekasi City

In the study, the method of data collection is meticulously outlined. Both primary and secondary data were utilized. Primary data, such as the drone propeller setup time, drone calibration time, and the travel time of land vehicles from the Main Gathering Point to the Stopover Point, were obtained through direct field observations. Additionally, the travel time between Stopover Points was sourced from Google Maps. On the other hand, secondary data was acquired from previous research results concerning the mapping route determination of flood-affected areas in Bekasi City using a combination of land vehicles and drones. Then, the study presents a conceptual model that serves as a blueprint, illustrating how different elements interact in the process of mapping flood-affected areas. This model simplifies the real-world system, making it easier for readers to understand. It essentially provides a visual guide, referenced as Figure 3 in the document, to show how drones and vehicles can be used together for effective mapping in disaster zones.



(a)



(b)

Figure 2. Data collection on drone setup time (a) and mapping time (b)

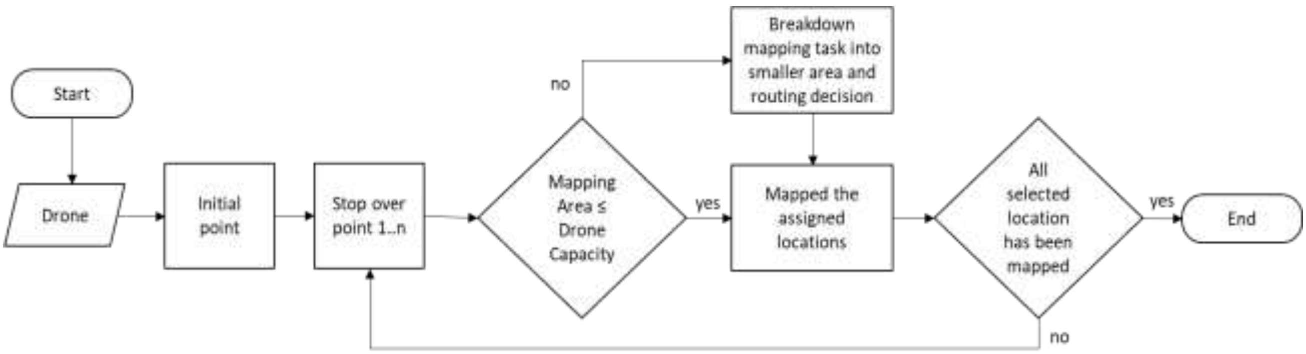


Figure 3. Conceptual model

The study outlines a structured approach to implementing the simulation model. The simulation model aligned with the previously established conceptual model, utilising the data gathered during the research. To ensure the accuracy and reliability of the simulation model, two critical steps were undertaken: verification and validation. The verification process aimed to confirm that the simulation model accurately reflected its conceptual counterpart. This was achieved using the tracing technique through the ProModel software, ensuring that all processes were consistent with the pre-established conceptual model. On the other hand, validation was conducted to ascertain that the conceptual model genuinely represented the real-world system. This was done by applying extreme conditions to the entity arrival elements to observe the model's response to these conditions. The model's successful response indicated its validation.

4. RESULT AND DISCUSSION

For simulation purposes, the study made use of the ProModel program. ProModel is a discrete-event simulation program that makes modeling easier. Furthermore, the Stat-Fit function inside the ProModel program was used to estimate the fitting distribution of the obtained data. This tool is useful for determining whether a certain batch of data adheres to a specific distribution.

Figure 4 depicts in detail the simulation model built using the ProModel application. The study's simulation findings, shown in Table 1, indicate the efficacy of the suggested approach for mapping flood-affected areas in Bekasi City. The simulation was run under a variety of scenarios with varied durations and vehicle numbers. The Simrunner function of the ProModel program is used for the optimization simulation. Six automobiles were judged to be the optimal number for a scenario lasting 20 hours. When the simulation time was reduced to 16 hours, the optimal number of automobiles increased to seven. This implies that a shorter simulation time need a bigger number of automobiles for efficient mapping. The findings demonstrate the optimal balance of simulation duration and required resources for effective mapping outcomes.

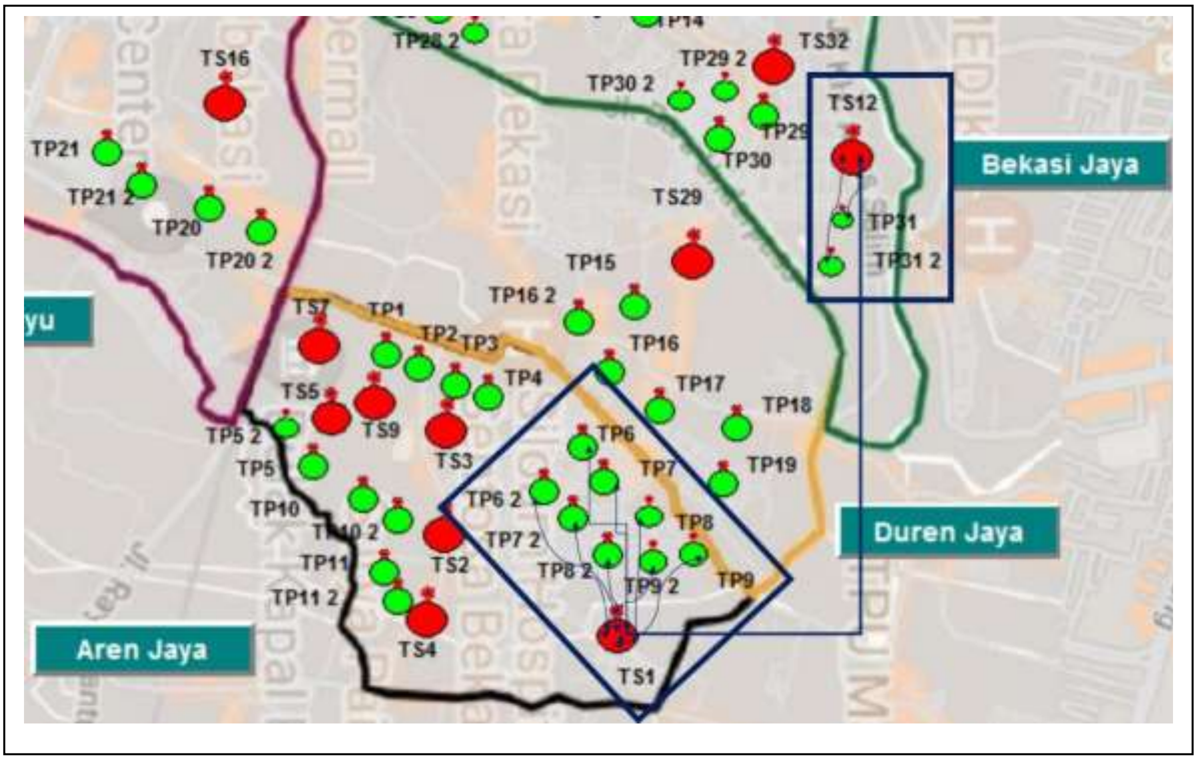


Figure 4. Promodel is used to illustrate the simulation model.

Table 1. Simulation Results

Simulation Time (hours)	Drone	Avg. Operation Time (minutes)	Number of Resources
20	1	702.891	6
	2	588.970	
	3	676.902	
	4	582.826	
	6	563.598	
	7	311.846	
16	1	552.342	7
	2	433.094	
	3	541.267	
	4	451.612	
	5	482.905	
	6	413.734	
	7	235.817	

5. CONCLUSION

The study used a discrete simulation model to map flood-damaged regions in Bekasi City. With three cars in use, the original simulation model ran for twenty-four hours. This highlighted the need for a more effective method of mapping places using drones in less time. In response, the study suggested ways to improve the situation, such as boosting the number of land vehicles and shortening the mapping time. Six automobiles were judged to be the optimal number for a 20-hour operating time scenario. The optimal number of cars for a scenario with a running time of 16 hours was seven. The findings emphasize the need of balancing simulation duration and resource allocation in order to get successful mapping results.

The work proposes many avenues for future research to improve the discrete simulation model for mapping disaster-affected areas. First, when developing the simulation model, account for variable situations during mapping during both the conveyance of drones using ground vehicles and drone flight. Second, upgrading the simulation model by incorporating meteorological conditions into the mapping process. Finally, consider modifying the mapping route if the number of mapping trucks changes. The purpose of these proposals is to improve the present model by addressing potential issues and enhancing the mapping process for future investigations.

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