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Prediction of fire evacuation in high-buildings junior high school using discrete event simulation

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ABSTRACT

Indonesia is included in the category of countries with high disaster risk, including the risk of fire disasters. However, the lack of public awareness makes planning risks greater, such as physical losses, minor injuries, and even fatalities. Therefore, good mitigation is needed to reduce this risk. The research aims to propose disaster mitigation for fires in high-buildings. One thing that can reduce casualties is evacuation. The success of an evacuation can be seen from the evacuation time. The research locus is one of the elementary schools in Serang City with a two-story building. The Discrete Event Simulation (DES) approach is used when experiencing a particular event. The data taken is data on the number of students and teachers, data on evacuation times using stairs or vertical evacuation methods with a certain distribution according to actual data. There are 2 scenarios used in the simulation, namely (1) evacuation using the available stairs, and (2) evacuation using a combination of stairs for men and vertical evacuation tools for women. The evacuation system using stairs in the school building was not effective because it took 5.17 minutes, while the speed at which the fire spread was 4.30 minutes. Evacuation using scenario 2 - a combination of stairs and vertical evacuation chute - resulted in a faster evacuation time of 3 minutes. Thus, the results obtained provide a suggestion for carrying out evacuation using a combination of using stairs and using a vertical evacuation chute.

ABSTRAK

Indonesia termasuk dalam kategori Negara dengan risiko bencana yang tinggi termasuk risiko bencana kebakaran. Namun kurangnya kesadaran masyarakat membuat risiko berncana semakin besar seperti kerugian fisik, luka ringan, sampai korban jiwa. Oleh karena itu diperlukan mitigasi yang baik dalam mengurangi risiko tersebut. Penelitian bertujuan untuk mengusulkan mitigasi bencana terhadap kebakaran pada gedung bertingkat. Salah satu yang dapat mengurangi korban adalah dengan evakuasi. Kesuksesan evakuasi adalah dengan dilihat dari waktu evakuasi Lokus penelitian adalah salah satu Sekolah Dasar di Kota Serang dengan gedung berlantai dua. Pendekatan *Discrete Event Simulation* (DES) merupakan sebuah metode kejadian diskrit yang digunakan ketika mengalami sebuah kejadian (*event*) tertentu. Data yang diambil adalah data jumlah siswa dan guru, data waktu evakuasi baik menggunakan tangga maupun metode alat evakuasi vertikal dengan distribusi tertentu sesuai dengan data aktual. Ada 2 skenario yang digunakan pada simulasi yaitu (1) evakuasi dengan menggunakan anak tangga yang tersedia, dan (2) evakuasi dengan kombinasi anak tangga untuk laki-laki dan alat evakuasi vertikal untuk perempuan. Sistem evakuasi dengan anak tangga pada gedung sekolah tidak efektif karena memperoleh waktu 5.17 menit, sedangkan kecepatan waktu api dalam merambat 4.30 menit. Evakuasi dengan skenario 2-kombinasi anak tangga dan *vertical evacuation chute*- menghasilkan waktu evakuasi lebih cepat yaitu 3 menit. Dengan demikian, hasil yang diperoleh adalah memberikan usulan untuk melakukan evakuasi dengan kombinasi menggunakan tangga dan menggunakan *vertical evacuation chute*.

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1. Introduction

Indonesia is one of countries in high-risk disasters. The disasters consist of natural, non-natural and social disasters [1]. One of the disasters that we need to be aware of is fire disaster. Fire is described as a disaster that occurs due to human negligence and natural factors such as lightning, extreme temperature increases, and other natural disasters that provide the potential for fire to form and cause fires [2]. Losses resulting from fires are not only material, building, or economic losses but also minor injuries and even loss of life. These natural conditions require the Indonesian people to always be alert. Preparedness must be carried out by both groups and individuals, including school-aged children, but this has not been seen in the field [3]. There is still weakness in preparedness particularly in application when disaster occurs [4]. Furthermore, the lack of awareness in society support the high risk condition [5].

Therefore, preparedness is a key, particularly in evacuation planning. Evacuation is one of the factors that need to be considered in safety standards [6]. Effective evacuation is an effort to minimize the incidence of casualties during and after a disaster occurs. In this case, both individuals and groups must have preparedness while disasters occur, including fire disasters. Disaster evacuation will be more crucial in school buildings because most of the children are the most vulnerable during and after a disaster, including physical, psychological, and educational disorders [7]. In addition, the character of fire in a fire disaster has a very short critical time. The fire was able to consume the entire building within 4 minutes and 30 seconds. Thus, the target evacuation time for a fire disaster is less than the critical time.

An approach that can be taken to determine evacuation time can be done by modeling using Discrete Event Simulation (DES). The DES is the proper approach to create random models according to real conditions and also as an experimental approach from real models with various scenarios so that it supports making appropriate strategic decisions [8]. The DES approach is widely used in various evacuation models such as emergency evacuation on airplanes [9], fire drills on boards [10], and fire evacuation in high nursing home buildings [11].

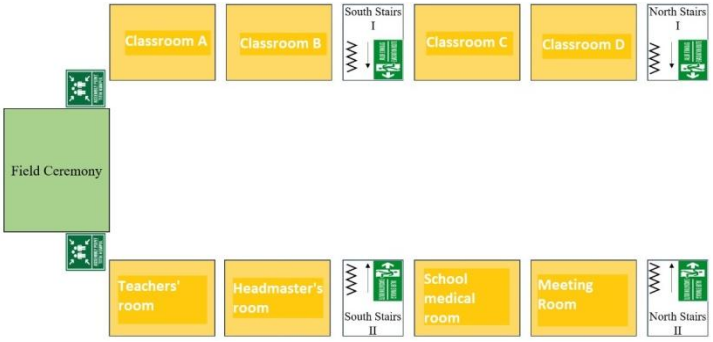
Evacuation in high-buildings has become a focus of various researchers, and this evacuation can use tools, namely stairs [12], [13], in some cases elderly people and people with disabilities use elevators [11][9], and several other vertical evacuation tools [13] such as innovation in the form of vertical escape chutes [14].

Research regarding the evacuation of high buildings in schools still needs to be carried out using the DES approach. Therefore, this research fills the gap regarding effective fire evacuation simulations in terms of time evacuation in school buildings using DES based on a critical time of less than 4 minutes 30 seconds.

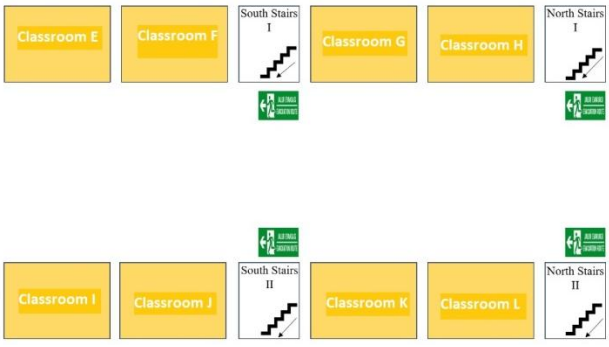
2. Research Methodology

2.1. Research Design

This study uses a quantitative approach. This research was located in a high building at one of the elementary schools in Serang City. Data collected are the layout of the school building and evacuation time (female teachers, female students, male teachers, and male students). Evacuation time is measured from time movement from the first and second floor to the assembly point. The building facility layout of the junior high school consists of first floor and second floor as shown in figure 1. In first floor consists of four classrooms, one teachers' room, one headmaster's room, one school medical room and one meeting room. In second floor consists of eight classrooms.



(a) 1st Floor of facility layout



(b) 2nd Floor of facility layout

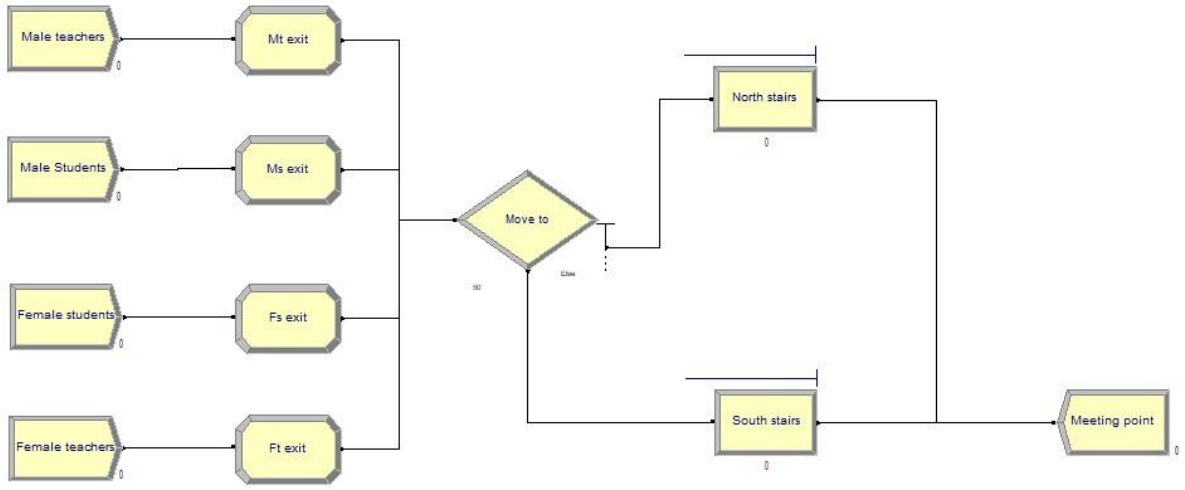
Figure 1. Facility layout of a junior high school in Serang City: (a) 1st floor and (b) 2nd floor

Evacuation time is measured using stopwatch for all member evacuees (female teachers, male teachers, female students, and female students). Data was taken from each category with repetition 20 times. The data is tested for uniformity and data adequacy using statistical methods. Then fit the data distribution for each of these data. The data analysis was carried out using discrete event simulation by validating and verifying the model.

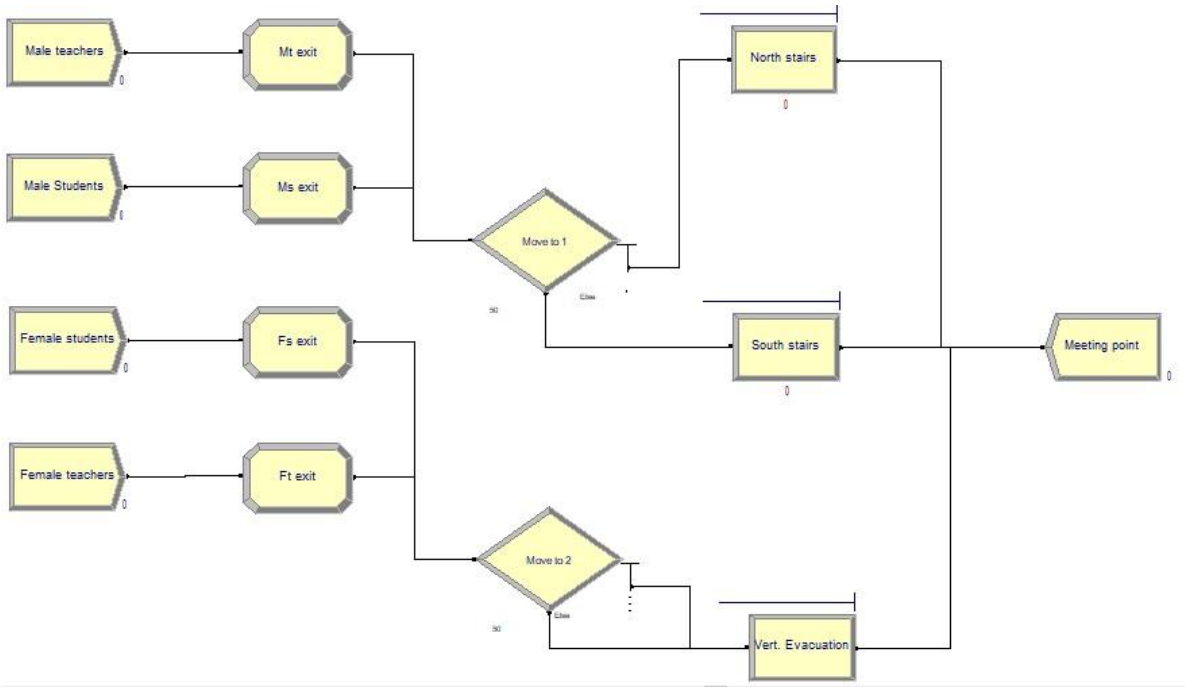
Discrete event simulation is a system modeling approach that is suitable for analyzing discrete processes, such as manufacturing systems, transportation, service queues, and so on. In discrete event simulation, changes in the state of the simulation model occur at discrete times caused by events. Common events in simulations are the arrival of an entity to a workstation, resource failure, completion of an activity, and the end of a shift. One of the advantages of the discrete event simulation approach is that it can model probabilistic events. Discrete Event Simulation is the modeling of systems in which variables only change at a series of discrete points in time [15]. This point or point is the time at which an event occurs, where an event is described as an instantaneous event that can change the state of the system [16]. The simulation model is analyzed by numerical methods rather than by analytical methods.

The model deploys two evacuation methods, namely evacuation with stairs for all member evacuees (Figure 1.a) and evacuation with a combination of stairs for male teachers and students and a vertical escape chute for female teachers and students (Figure 1.b). In Figure 1.a, each one is ‘created’ for male teachers, male students, female students, and female teachers. Then ‘assign’ the exit activity for male teachers (Mt) exit, male students (Ms) exit, female students (Fs) exit, and female teachers (Ft) exit. ‘Decide’ is the decision for the member's choice to move with access north stairs or south stairs. And in the end 'dispose' is where the member evacuees are at the assembly point. Figure 1.b is a revision from the previous model in the ‘decision’ activity for moving member evacuees. The Mt and Ms move to stairs and the Fs and Ft move to vertical evacuation chute.

Validation is carried out by comparing simulation data with actual data using the Z statistical test. The step-by-step hypothesis is followed to have validation. Meanwhile, verification is carried out by confirming the fire disaster evacuation model with the school principal and teachers.



(a) Scenario 1



(b) Scenario 2

Figure 2. Conceptual model of fire evacuation: (a) Scenario 1: Evacuation with stairs (b) Scenario 2: Evacuation with vertical escape chute at Junior High School

2.2. Scenario Models

For the evaluation of fire evacuation, we build two scenarios (Table 1). The first scenario is existing model. The evacuation is with stairs for all members. The second scenario is proposed scenario for improving the evacuation time. The Scenario 2 is evacuation with stairs for male teachers and students and a vertical escape chute for female teachers and students because of the children or elder people walk slowly[17]. Evacuation speed is calculated from the number of evacuation speed follow the data and their distribution.

Table 1. Scenarios for evacuation method

No	Scenarios	Evacuation method	Evacuation speed
1	Scenario 1	with stairs (All members)	based on speed each member (Table 3)
2	Scenario 2	Combined stairs (for male teachers and students) and vertical escape chute (for female teachers and students)	based on speed each member (Table 3)

3. Result and Discussion

We obtained evacuation time data for all members from direct measurements as shown in Table 2. Figure 3 depicts the evacuation time for male students is fastest than the other evacuees with 19 seconds on average. Meanwhile, the evacuation time of female students is the slowest of the others with 21 seconds on average. It happened because all evacuation members prioritized students first, then teachers. Moreover, the female students took longer to evacuate because they were unable to compete with other evacuees, and they chose to give in.

Table 2. Evacuation time for all members

No	Evacuation time (minute)			
	Female teacher	Male Teachers	Female students	Male students
1	20.3	24.3	19.2	24.9
2	25.3	23.2	19.8	17.2
3	23.9	21.2	25.7	21.2
4	24.3	19.2	25.1	18.1
5	23.6	19.8	25.8	18.6
…	…	…	…	…
…	…	…	…	…
…	…	…	…	…
18	17.2	16.4	18.7	17.1
19	18.3	16.1	17.3	23.2
20	18.9	24.9	19.5	19.2

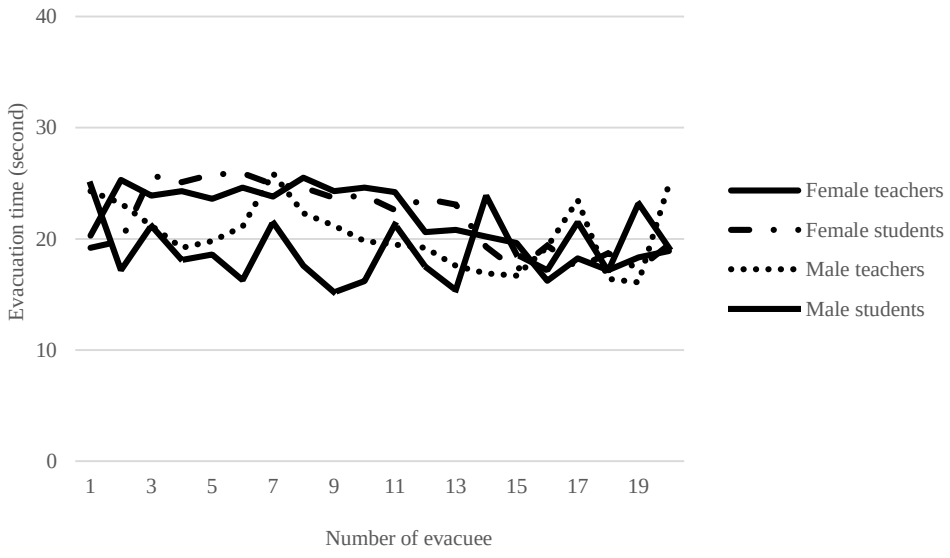


Figure 3. Evacuation time for all member evacuees

Then we validate and confirm the data. From the validation it was found that the simulation results were the same as the actual system. In addition, the model is verified by brainstorming and discussing it with the school principal and teachers. Next, we fit the data into distribution data to become the

initial data for discrete event simulations in scenario 1 and scenario 2 (Table 3). Based on scenario 1 and scenario 2, a fire disaster simulation was conducted for all members.

Table 3. Fitting the Data of Evacuation

Evacuation time	Mean	Std. Dev.	Distribution	Expression
Female teachers	24.1	1.19	Normal	NORM(24.1, 1.16)
Male teachers	20.4	0.503	Normal	NORM(20.4, 0.49)
Female students	24.9	1.33	Normal	NORM(24.9, 1.3)
Male students	16.5	0.827	Normal	NORM(16.5, 0.806)
Stairs 1	24.5	1.32	Beta	21.5 + 7 * BETA(2.63, 3.5)
Stairs 2	18.4	2.09	Beta	14.5 + 7 * BETA(0.996, 0.769)
Vertical evacuation chute	2.55	0.51	Beta	1.5 + 2 * BETA(2.11, 1.93)

The critical time for a fire disaster is 4 minutes 30 seconds. It means the evacuation time for all members has to reach the critical time in order to create successful evacuation. Based on simulation, the rescue time using a stairs is 5 minutes 17 seconds and the rescue time for a combination of a stairs and a vertical escape chute is 3.0 minutes (Figure 4.) The time evacuation using stairs is slower than combination stairs and a vertical escape chute. In many situations, the high-building evacuation needs more stairs to avoid congestion at the exit way and may be increase of time evacuation [18]. Thus, the effective evacuation time resulted from using a combination of stairs with a vertical escape chute based in terms of evacuation time required being less than the critical time for a fire disaster. Moreover, it can reduce the number of fatalities. Furthermore, there is still lack of analysis because of the unorganized un-organized evacuation result the crowd and incorrect evacuation route, such as severe congestions [19].

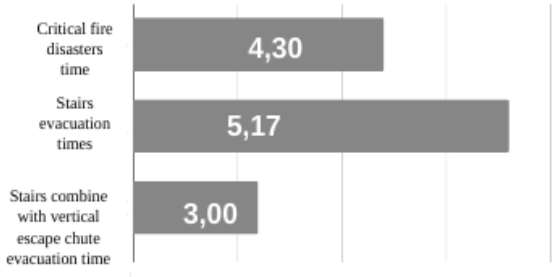


Figure 4. Comparison time of critical fire disaster, stairs evacuation, and vertical chute escape evacuation

4. Conclusion

This research predicts evacuation scenarios for fire disaster in high buildings. Evacuation scenario using stairs takes 5.17 minutes to evacuate all members (teachers and students). Meanwhile, evacuation scenario using stairs and a vertical escape chute takes 3.00 minutes to evacuate all members. Evacuation using stairs combined with a vertical escape chute creates faster evacuation time than another scenario under critical time for a fire disaster. In summary, evacuation with stairs and vertical escape chutes is an effective way to evacuate from fire cases in a high-building context. This research has limitations in not considering aspects of unorganized evacuation, such as piling up on one side due to chaos during the evacuation.

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