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Designing Evacuation Route Using DIJKSTRA Methods

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Abstract – The safety of building occupants is a top priority while a disaster, for this reason, the availability of evacuation facilities and evacuation route maps is something that must be considered. To avoid the risks that occurred by disasters, the researchers designed an evacuation route using Dijkstra's Algorithm method. In designing the evacuation route, an effective route should be chosen so evacuation can be carried out quickly. To determine the travel time required data speed and distance to the assembly point, so the travel time of each route, then the fastest route is selected. From the design outputs, the location of the assembly point is determined on the top page. Knowing the fastest route, then an evacuation route map is made so that school building users more easily to get the assembly point.

Keywords – Evacuation Capacity, Evacuation Time, Dijkstra's Algorithm.

I. INTRODUCTION

The safety of building occupants is certainly a top priority when a disaster occurs, for this reason, the existence of evacuation facilities and evacuation route maps is something that must be considered. Evacuation facilities can at least minimize the possibility of fatalities for building occupants in the event of a disaster [1]. Provisions regarding evacuation routes in each building have been contained in the government regulation of the Republic of Indonesia Number 36 of 2005 article 59 paragraph (1), it is explained that "Every building, except for single dwelling houses and simple row houses, must provide evacuation facilities which include a hazard warning system for users, emergency exits and evacuation routes can provide convenience for building users to safely evacuate from inside the building in the event of a disaster or emergency"[2]

In designing an evacuation route, an effective route must be chosen so that evacuation can be carried out quickly. Path selection problem solving can be done in two ways, conventional and heuristic. The conventional method is an exact mathematical calculation method, including the Dijkstra Algorithm, Floyd-Warshall, and Bellman-Ford. The heuristic method applies an approach to selecting routes with optimization. Commonly applied heuristic methods are Genetic Algorithms, Ant Colony Algorithms, and others. This study uses the Dijkstra Algorithm method in determining the evacuation route. Dijkstra's algorithm applies the greedy principle, namely selecting the edge with a smaller weight to connect the selected node with other nodes that have not been selected.[3]

This research takes the case of the elementary school at Badung Bali which does not yet have an evacuation route map. Not infrequently there are still some school members who are near the building when a disaster such as an earthquake occurs. This happens due to a lack of insight regarding a safe distance from the building and the absence of clues that can direct them to a safe place. To avoid risks that can occur due to disasters, the researchers designed an evacuation route using the Dijkstra Algorithm method.

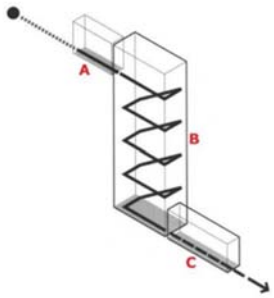
II. Sources of Research

2.1. Disaster

According to Law No. 24 of 2007, a disaster is an event or series of events that threatens and disrupts people's lives and livelihoods caused, both by natural factors and/or non-natural factors as well as human factors, resulting in human casualties, environmental damage, losses property, and psychological impact. Disasters can be caused by several factors including natural, technological, and human consequences [4].

2.2. Evacuation Facility

An evacuation facility is a continuous and unobstructed passageway from any point in the building to a street, yard, field, or other open space that provides safe access to a public road. Evacuation facilities may include vertical or horizontal passageways, rooms, doors, passages, corridors, balconies, ramps, stairs, lobbies, escalators, courts, and courtyards. Evacuation facilities consist of 3 main parts, namely exit access, exit, and exit discharge as shown in Figure 1.



A: Exit Access
B: Exit
C: Exit Discharge

Figure 1 Part of Evacuation Facilities

Sources: Peraturan Menteri PUPR No14 Tahun 2017

2.3. Graf and Path

A graf is a discrete structure consisting of a vertex and an edge, a graph is a set of pairs (V, E) where V is a non-empty set of vertices and E is an edge set that connects a pair of vertices in a graf [5]. One application of graf theory is to determine the shortest path in a graf. Applying the shortest path style is an optimization problem because the goal is to determine the minimum path length from one node to another. The graf that is used to determine the path length is a weighted graf, which is a graf that has a value in such a way that the total path length is the sum of each performance. If the selected path does not occur node repetition then the path is a path [6].

A path that starts and ends at the same node is called a circuit. Meanwhile, a path that starts and ends at the same node is called a cycle [7].

2.4. Evacuation Capacity

Evacuation capacity can be described by the ability of roads for people to pass to evacuate. The space for evacuation under normal conditions is about 1m^2 per person, the narrower the space for movement, the slower the speed of people running [8] Evacuation capacity can be formulated as follows:

$$Ev = \frac{W}{space} \times Velocity \qquad \text{.....(1)}$$

Ev = Evacuation Capacity (man/ hour)

W = Minimum Wide Access (meters)

Space = Space for people to walk quickly (m^2 /man)

Velocity = Everage velocity for people walking (km/ hour)

Based on the technical guidelines for planning temporary evacuation sites by the National Disaster Management Agency (BNPB), the standard speed for people walking fast is 3.3 km/hour, and space for running is 1 m^2/person [8]

2.5. Travel Time

The time for horizontal travel is calculated based on the estimated walking speed. The horizontal travel speed must be calculated using equation (2). If the calculated travel speed exceeds 1.2 m/s then the travel speed must be taken as 1.2 m/s. If the calculated travel speed is less than 1.2 m/s, then the calculated value will be used.

$S = k – akD$ ....(2)

S = Horizontal Travel Speed (meters/second)

D = Room density(man/m^2)

k = Constanta according Table 1

a = 0,266 for velocity with unit meters/second and density with unit man/m^2 [9].

For vertical trips, Equation 2 applies but the value used for k is a function of the steps and the size of the tread, with, Ttrav=Ltrav/S, Ttrav=travel time (S), and L trav=travel distance (m), according to Table 1.

Table 1 Maximum Travel Rate for Vertical and Horizontal Travel

Part of Exit Facilities		Velocity (m/s)	
Corridor, ramp, doors		1,4	1,2
Stairs (mm)	Stairs treads (mm)		
191	254	1	0,85
178	279	1,08	0,95
165	305	1,16	1
165	330	1,23	1,05

Sources: New Zealand-Ministry of Business Innovation & Employment, (2017)

Travel time is calculated using the equation as follows

Ttrav = Ltrav/S

Whereas Ttrav is Travel time in seconds and Ltrav is Travel distance in meters

2.6. Algoritma Dijkstra

Dijkstra's Algorithm works by calculating from the initial node to the nearest node, then to the second node, and so on [5]. Dijkstra's algorithm works by creating an optimal path at each step. Dijkstra's algorithm can be done in steps:

1. Choose the departure point, then determine the weight at the initial vertex to the directly connected vertex, Dijkstra will carry out the development of the search from one vertex to another and the next vertex step by step.
2. Give a weight value for each vertex to another vertex, then set a value of 0 to the initial vertex and an infinite value to other vertices (unfilled).
3. Set all untraveled points and set the starting point as “Departure node”.

4. From the departure node, select the neighboring nodes that have not been passed and calculate the total weight from the departure point. If the weight is less than the previous total weight (which has been previously recorded), delete the old data, and replace it with the new weight data.
5. When we finish considering each weight to the neighboring nodes, mark the nodes that have been passed as "Nodes skipped". The node that is passed will never be checked again, the data stored in the last data has the smallest weight.
6. Set "Node not passed" with the smallest weight (from the departure node) as the next "Departure Node" and repeat step 5.

Planning regarding evacuation routes using the Dijkstra Algorithm method has been carried out before [10]. The purpose of this research is to design a fire evacuation route map and the location of the marking using the Dijkstra Algorithm method to determine the shortest path and ISO 7010 concerning colors and safety signs. The results and discussion of the research consisted of observing evacuation routes and marking them, and designing fire evacuation routes and marking them. After measuring the shortest path distance, then determine the markings to be used on the evacuation route. The reference used in this study is the ISO 7010:2012 standard.

Furthermore, research on the application of Dijkstra's Algorithm to determine the shortest path was conducted [11]. The aim is to determine the optimal mileage to distribute goods from PT. X to PT. Y and PT. Z. To minimize the cost of goods distribution, PT. X must determine an adequate route by considering the optimization of transportation costs. One of the variables that affect transportation costs is distance. This test uses data from Google Maps to find out the distance to each destination, making it easier to find the shortest path.

III. RESEARCH METHODS

3.1. Data Collection

This design requires some data. The primary data obtained through interviews is the capacity of each room. While the survey was conducted to obtain data on the length of the route to be traversed for evacuation. The secondary data needed in designing an evacuation route is a school plan, with this data the paths that can be traversed and the location of each room can be determined as shown in Figure 2 and Figure 3.

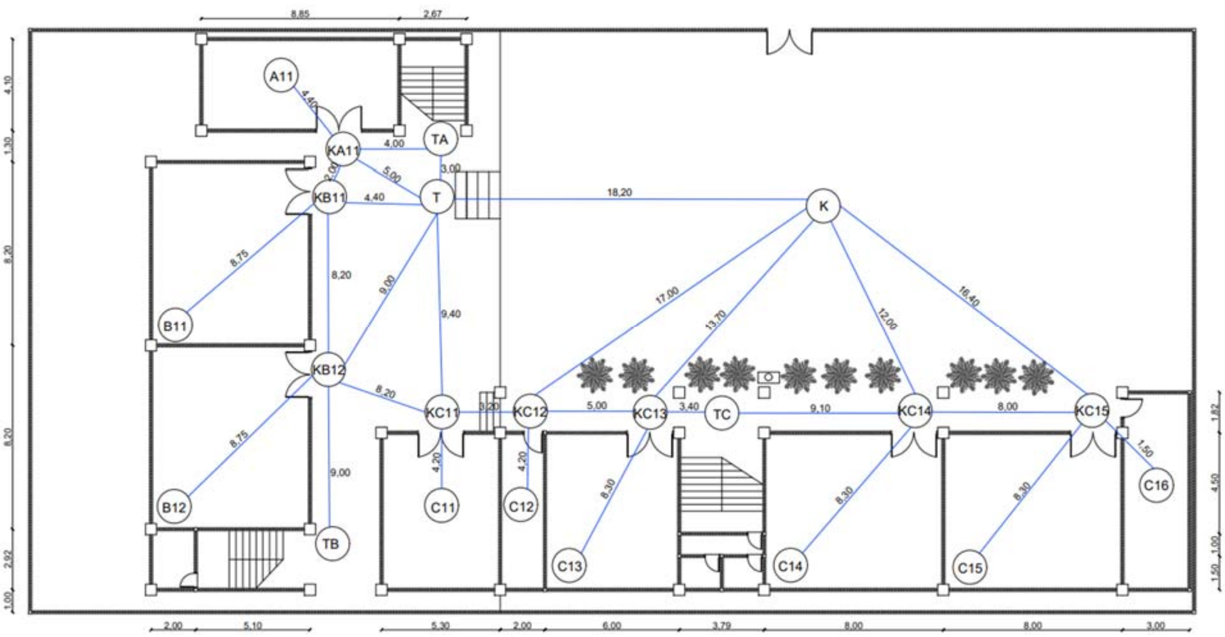


Figure 2 First Floor Plan

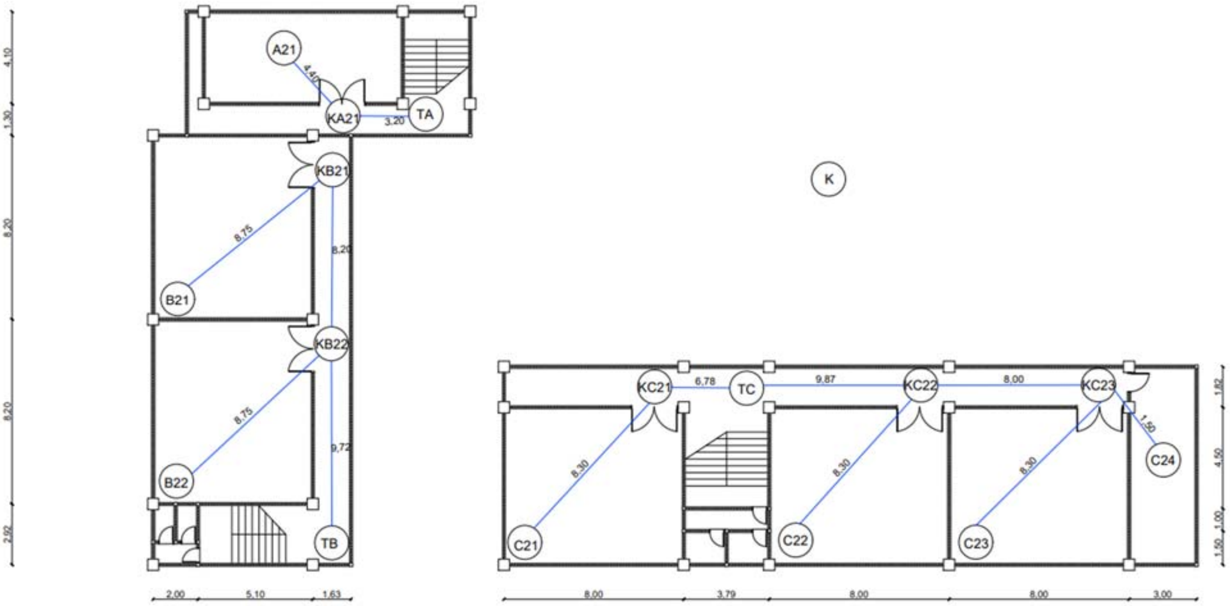


Figure 3 2nd Floor Plan

3.2. Determine Evacuation Route

From the floor plan of the elementary school in Badung Bali, it can be seen the location and area of each room as well as the existing access routes. Once the case study plan is known, the next step is to take measurements. The steps for measuring and determining the weight of the track with Dijkstra's Algorithm are as follows:

1. Prepare a measuring tool with a length of 50 meters.
2. Measurement starts from the distance of the room to the corridor.
3. Then, measure the distance of the corridor leading to the stairs.
4. Next, measure the distance from the stairs to the assembly point.
5. Based on the data that has been obtained, an analysis of evacuation time is carried out based on speed and distance.
6. Evacuation time data is processed using Dijkstra's Algorithm, this data can be presented in the form of a time calculation table.
7. Get the fastest route to a safe gathering point.

IV. Analysis and Recommendations

4.1. Assembly Point Position

The gathering point for the school building is planned on the top page. The location was chosen as a gathering area because it met the criteria of NFPA 101 of 2000, including having a distance of 6.1 meters and being safe from falls and hazards, the selected location has access to a safer place and does not hinder vehicles from handling hazards [12].

4.2. Evacuation Route Capacity

Evacuation time can be described as travel time which is calculated based on speed and distance between vertices. Speed is calculated based on the density of the evacuation route which begins with the calculation of the capacity of the evacuation route. The following is the recapitulation of the calculation of the capacity of the evacuation route shown in Figure 2 and Figure 3 Floor plans for the 1st and 2nd floors of Elementary school in Badung as shown in Table 2 and Table 3.

Table 2 Evacuation Route Capacity

No	Route	Ev
1.	KA11-TA	1
2.	TA-T	1
3.	T-K	2
4.	KA11-T	1
5.	KB11-KA11	1
6.	KB11-T	2
7.	KB12-KB11	1
8.	KB12-T	1
9.	T	2
10.	TB-KB12	1
11.	KB12-KC11	1
12.	KC11-T	1
13.	KC11-KC12	2
14.	KC12-K	1
15.	KC12-KC13	2

Table 3 Evacuation Route Capacity

No	Track	Ev	No	Track	Ev
1.	KA11-TA	1	16	KC13-K	1
2.	TA-T	1	17	TC-KC13	2
3.	T-K	2	18	TC-KC14	2
4.	KA11-T	1	19	KC14-K	1
5.	KB11-KA11	1	20	KC14-KC15	2
6.	KB11-T	2	21	KC15-K	1
7.	KB12-KB11	1	22	KA21-TA	1
8.	KB12-T	1	23	TA	1
9.	T	2	24	KB21-KB22	1
10	TB-KB12	1	25	KB22-TB	1
11	KB12-KC11	1	26	TB	1
12	KC11-T	1	27	KC21-TC	2
13	KC11-KC12	2	28	TC	1
14	KC12-K	1	29	KC22-TC	2
15	KC12-KC13	2	30	KC2223-KC22	2

4.3. Room Density and Evacuation Route

The density of evacuation routes (D) is the result of the number of people divided by the area. The number of people on the evacuation route is assumed to be the same as the capacity of the evacuation route, as shown in Table 4 and Table 5.

Table 4 Rooms Density

No	Rooms	Total of People	Area (m2)	D (people/m2)
1.	A11	6	36,29	0,17
2.	B11	29	58,22	0,50
3.	B12	29	58,22	0,50
4.	C11	6	37,10	0,16
5.	C12	3	14,00	0,21
6.	C13	14	42,00	0,33
7.	C14	29	56,00	0,52
8.	C15	29	56,00	0,52
9.	C16	5	26,40	0,19
10.	A21	6	36,29	0,17
11.	B21	29	58,22	0,50
12.	B22	29	58,22	0,50
13.	C21	29	56,00	0,52
14.	C22	29	56,00	0,52
15.	C23	29	56,00	0,52
16.	C24	5	26,40	0,19

Table 5 Evacuation Route Density

No	Route	People	Area (m2)	D(man/ sec)	No	Route	People	Area (m2)	D(man/ sec)
1	KA11-TA	1	5,20	0,23		KC13-K	1	15,72	0,07
2	TA-T	1	3,60	0,31		TC-KC13	2	6,22	0,27
3	T-K	2	40,04	0,05		TC-KC-14	2	16,65	0,10
4	KA11-T	1	6,00	0,18		KC14-K	1	13,68	0,08
5	KB11-KA11	1	2,40	0,46		KC14-KC15	2	14,64	0,11
6	KB11-T	2	10,08	0,20		KC15-K	1	18,96	0,06
7	KB12-KB-11	1	13,37	0,11		KC21-TA	1	5,12	0,21
8	KB12-T	1	36,00	0,04		TA	1	10,00	0,11
9	T	2	4,20	0,46		KB21-KB22	1	13,37	0,11
10	TB-KB12	1	13,37	0,11		KB22-TB	1	18,18	0,08
11	KB12-KC11	1	9,84	0,11		TB	1	13,61	0,08
12	KC11-T	1	10,56	0,10		KC21-TC	2	14,33	0,12
13	KC11-KC12	2	5,98	0,28		TC	1	14,45	0,10
14	KC12-K	1	19,68	0,06		KC22-TC	2	20,00	0,08
15	KC12-KC13	2	9,15	0,18		KC23-KC22	2	1464	0,11

4.4. Travel Time in the Evacuation Route

Travel time is obtained via distance divided by speed as shown in Table 6.

Table 6 Travel Time From Room to Corridor

No	Rooms	Ltrav(m)	S(m/s)	Ttrav(S)	No	Rooms	Ltrav(m)	S(m/s)	Ttrav(S)
1.	A11	4,4	1,2	3,67	9.	C16	1,5	1,2	1,25
2.	B11	8,75	1,2	7,29	10.	A21	4,4	1,2	3,67
3.	B12	8,75	1,2	7,29	11.	B21	8,75	1,2	7,29
4.	C11	4,2	1,2	3,5	12.	B22	8,75	1,2	7,29
5.	C12	4,2	1,2	3,5	13.	C21	8,3	1,2	6,92
6.	C13	8,3	1,2	6,92	14.	C22	8,3	1,2	6,92
7.	C14	8,3	1,2	6,92	15.	C23	8,3	1,2	6,92
8.	C15	8,3	1,2	6,92	16.	C24	1,5	1,2	1,25

Table 7 Travel Time in Evacuation Route

No	Track	Ltrav(m)	Ttrav(S)	No	Track	Ltrav(m)	Ttrav(S)
1.	KA11-TA	4	3,33	16.	KC13-K	13,7	11,68
2.	TA-T	3	2,50	17.	TC-KC13	3,4	2,83
3.	T-K	18,2	15,17	18.	TC-KC14	9,1	7,58
4.	KA11-T	5	4,17	19.	KC14-K	12	10,26
5.	KB11-KA11	2	1,67	20.	KC14-KC15	8	6,67
6.	KB11-T	4,8	4,00	21..	KC15-K	16,4	13,93
7.	KB12-KB11	8,2	6,83	22.	KA21-TA	2	1,67
8.	KB12-T	9	7,50	23.	TA	8,22	8,22
9.	T	2	2,00	24.	KB21-KB22	8,2	6,83
10.	TB-KB12	6,8	5,67	25.	KB22-TB	8,52	7,10
11.	KB12-KC11	8,2	6,83	26.	TB	8,44	8,44
12.	KC11-T	9,4	8,37	27.	KC21-TC	4,9	4,08
13.	KC11-KC12	4	3,82	28.	TC	9,97	9,97
14.	KC12-K	17	14,43	29.	KC22-TC	8	6,67
15.	KC12-KC-13	5	4,17	30.	KC23-KC22	8	6,67

Table 8 is the calculation of the evacuation time needed for one person from each room to the gathering point.

Table 8 The Fastest Time to Assembly Point

No	Initial Vertex	Route	Total Time (sec)
1.	A11	A11-KA11-T-K	25,01
2.	B11	B11-KB11-T-K	28,46
3.	B12	B12-KB12-T-K	31,96
4.	C11	C11-KC11-KC12-K	21,76
5.	C12	C12-KC12-K	17,94
6.	C13	C13-KC13-K	18,61
7.	C14	C14-KC14-K	17,19
8.	C15	C15-KC15-K	20,86
9.	C16	C16-KC15-K	15,19
10.	A21	A21-KA21-TA-T-K	33,22
11.	B21	B21-KB21-KB22-TB-KB12-T-K	62,17
12.	B22	B22-KB22-TB-KB12-T-K	47,23
13.	C21	C21-KC21-TC-KC13-K	32,66
14.	C22	C22-KC22-TC-KC13-K	38,08
15.	C23	C23-KC23-KC22-TC-KC13-K	44,74
16.	C24	C24-KC23-KC22-TC-KC13-K	39,08

4.5. Total Evacuation Time

The limited capacity of the evacuation routes to be traversed resulted in delays. The delay time is obtained by adding up the time it takes to go through one vertex minus the time it takes the next vertex to move. The time needed to go through the KB21 vertex to the next vertex, namely KB22 with a total of 29 individuals, is 198.17 seconds. Meanwhile, the time needed by 29 people at the KB22 vertex to TB was 205.90 seconds. So that the delay time on KB22 is 7.73 seconds. The time needed for 29 people to go through TB is 244.76 seconds, and the delay time obtained is 38.86 seconds.

In the South Building, there are several time delays on the 2nd floor. The time delay on KC22 to TC is 37.46 seconds. Then delay on TC for 155 seconds. The delay will also affect other corridors that are directly related to the corridor.

The maximum time required for evacuation is obtained, which is 1702.97 seconds according to Table 9. This time is the fastest and most optimal time to evacuate all occupants of the building to the gathering point, so they are safe from danger [13][14]. After obtaining the fastest route, an evacuation route map is then made to make it easier for building users to gather safely.

Table 9 Total Evacuation Time

No	Initial Vertex	Route	Total Time (sec)
1.	A11	A11-KA11-T-K	98,50
2.	B11	B11-KB11-T-K	518,38
3.	B12	B12-KB12-T-K	738,29
4.	C11	C11-KC11-KC12-K	140,46
5.	C12	C12-KC12-K	53,82
6.	C13	C13-KC13-K	260,50
7.	C14	C14-KC14-K	498,52
8.	C15	C15-KC15-K	604,85
9.	C16	C16-KC15-K	674,55
10.	A21	A21-KA21-TA-T-K	144,00
11.	B21	B21-KB21-KB22-TB-KB12-T-K	1575,62
12.	B22	B22-KB22-TB-KB12-T-K	1355,70
13.	C21	C21-KC21-TC-KC13-K	929,02
14.	C22	C22-KC22-TC-KC13-K	1208,83
15.	C23	C23-KC23-KC22-TC-KC13-K	1547,85
16.	C24	C24-KC23-KC22-TC-KC13-K	1702,97

The maximum time required for evacuation is obtained, which is 1702.97 seconds. After obtaining the fastest route, an evacuation route map is then made to make it easier for building users to reach a safe gathering location.

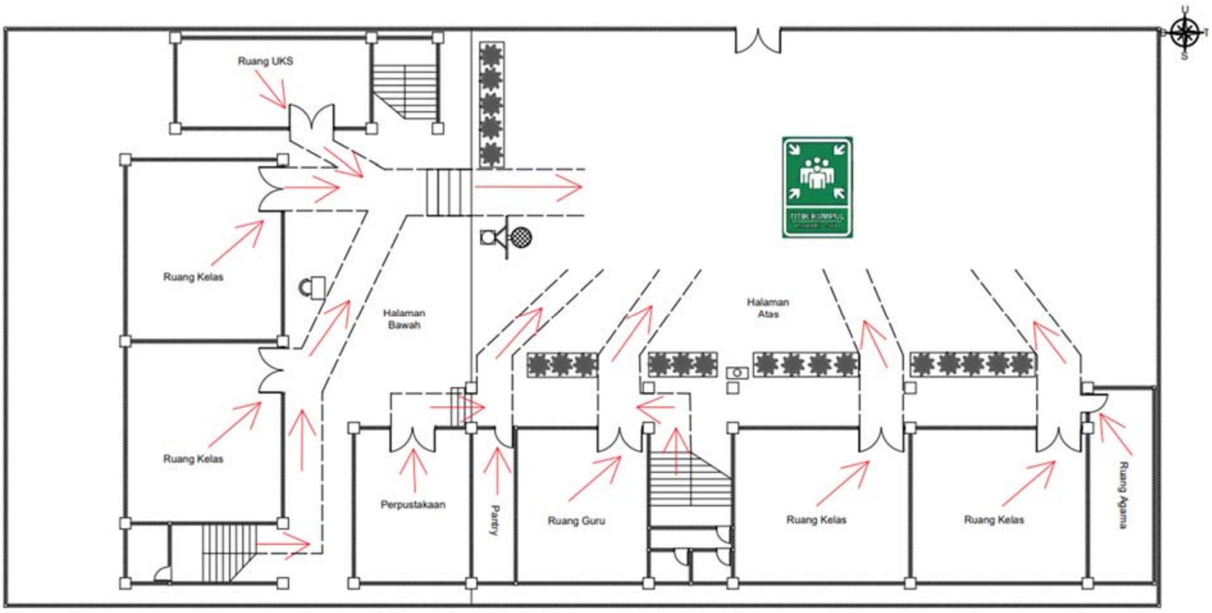


Figure 4 1st Floor Evacuation Route

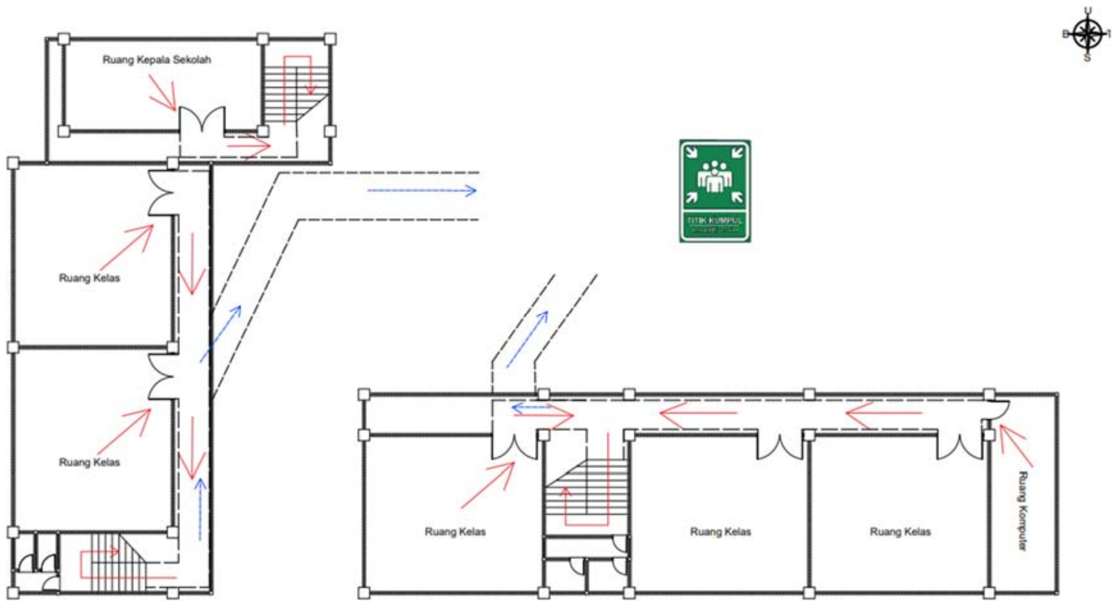


Figure 5 2nd Floor Evacuation Route

V. CONCLUSION

The evacuation route at Elementary School in Badung is designed using the Dijkstra Algorithm method. The results of the design are:

1. In the UKS room, the path chosen to get to the gathering point is by crossing the corridor in front of the UKS room and then down the stairs to the upper courtyard.
2. For classrooms on the 1st floor of the west building, the path chosen to get to the gathering point is to cross the corridor in front of the classroom and than to the stairs to the lower courtyard to the upper courtyard.
3. In the library room, the path chosen is to cross the corridor in front of the library room, then to the corridor in front of the pantry than to the gathering point.
4. In the pantry, the path chosen is to cross the corridor in front of the pantry, then to the gathering point.
5. In the teacher's room, the path chosen is to cross the corridor in front of the teacher's room, then to the gathering point.
6. For classrooms and religious rooms on the south building floor 1, the path chosen is to cross the corridor in front of each classroom, then head to the gathering point.
7. In the principal's room, the path chosen is to cross the corridor then head to the north building stairs, then to the lower courtyard stairs to the upper courtyard.
8. For classrooms on the 2nd floor of the west building, the path chosen is to cross the corridor to the stairs of the west building, then to the classroom corridor.
9. west building 1st floor, then to the lower courtyard stairs to the upper courtyard.
10. For classrooms on the 2nd floor of the south building, the path chosen is to cross the corridor in front of each classroom to the stairs of the west building, then to the teacher's room corridor, then to the gathering point.

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