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Wayfinding Analysis for Evacuation Optimization with Urban Network Analysis in Disaster Preparedness School KB TK Masjid Syuhada

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ABSTRACT

The existence of evacuation routes is one of the most important elements in disaster management because it will determine the smoothness of the rescue process during a disaster. An evacuation route is a route to an assembly point or exit that is assumed to be a safe space. Wayfinding is the process of moving from one point to another within the closest or fastest distance. In relation to the evacuation process, wayfinding will show the movement from a point, which in relation to buildings can be a specific space, to an exit or assembly point. As one of the disaster preparedness schools in Yogyakarta's Special Region, Masjid Syuhada Kindergarten was chosen as the site of the research. It is a complex of schools ranging from playgroup, kindergarten, elementary school, to junior high school, all of which are connected by the Syuhada Mosque. The analysis of evacuation routes in the kindergarten was conducted using Urban Network Analysis (UNA). UNA is used as a method to determine the effectiveness of providing evacuation routes in a building area because it can analyze trips between points, called origin and destination. Of the various analyses that UNA can perform, this research uses the closest facility analysis. In this study, the origins were all the class in the kindergarten which placed at the door as the open access and in the middle of the class if the class have two doors; while the destinations were the stairs which heading to assembly point. The conclusion is reached after analyzing the network that connects the origin of the class to the destination of the stairs, which is connected to the assembly point.

1. Introduction

Geographically, the Special Region of Yogyakarta is divided into four physiographic units: Mount Merapi, the Sewu or Thousand Mountains, the Kulon Progo Mountains, and the Lowlands, which are crossed by the Opak Fault, the source of the devastating earthquake in Yogyakarta in 2006 [1]. Table 1 shows the disaster risk index for each district and city from 2018 to 2021, with two districts, Kulon Progo and Bantul, having a high-risk index. In response to the province's risk index value the Government of Yogyakarta Special Region launched Disaster Preparedness Schools in 55 schools across the province, ranging from elementary to high schools, as every area in the province is prone to disasters in November 2022.

This effort aims to better prepare individuals in terms of disaster awareness and preparedness starting from school [2]. To maximize the effectiveness, implementation and sustainability of the program, it requires active participation of school members and integration of the program throughout the school, including the use of the school environment. Schools, as children's second home, where they spend a lot of time, and where they experience the development of growth and cognitive/learning skills, self-regulation, and social-emotional learning [3][4]

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emphasize the importance of safe and disaster-prepared schools, both structurally and non-structurally.

This idea is supported by the Global Alliance for Disaster Risk Reduction and Resilience in the Education Sector [5], which has developed the Comprehensive School Safety Framework (CSSF) 2022-2030, an approach to protect children and education from all types of hazards and risks by providing a practical framework for governments. According to BNPB data in the last 15 years, 46,648 schools were affected by disasters in 2017, indicating that schools have not fully transitioned into safe, clean, healthy, child-friendly and fun environments [6]. Table 2 shows the various structural and non-structural facilities and infrastructure dimensions of disaster management [7], of which one is the availability of easy-to-understand evacuation access. The purpose of this study is to verify the effectiveness of evacuation routes in a facility versus its occupancy, in a disaster preparedness school located in Yogyakarta Special Region.

Table 1. Risk index value of Special Region of Yogyakarta (DIY) from 2018-2021 [1]

City/ district	2018	2019	2020	2021	2021 Risk Index
Kulon Progo	203.2	203.2	203.2	180.8	High
Bantul	187.2	187,2	187.2	157.3	High
Gunung Kidul	157.6	157.6	157.6	142.1	Med
Sleman	90.17	83.72	83.72	78.96	Med
Yogyakarta	73.00	72.86	72.86	72.57	Med

Note: unchanged risk index value due to constant capacity value trend

Table 2. Structural and non-structural dimensions of disaster management [7]

Aspects	Programs/Facilities/Policies
Structural	Strong and sturdy building structure Strong and stable furniture Flammable or fragile materials are stored safely Easy to understand evacuation access and availability of evacuation areas Availability of fire extinguishers and first aid kits Warning devices/signs in the school environment
Non-structural	School community disaster preparedness (students, teachers, institutions) Incorporating disaster awareness into the curriculum Establishing Disaster Preparedness Standards in schools Evaluation of current disaster preparedness in schools Improving the capacity of school communities to deal with disasters Availability of school extracurricular programs that support disaster preparedness (scouts, little doctors, etc.) Cooperation with disaster-related stakeholders Simulation exercise at school Policies that support the promotion of disaster preparedness in schools Creating a Disaster Response Plan at school

1.1 Evacuation Route

According to the Regulation of the Minister of Public Works and Public Housing of the Republic of Indonesia Number 14/PRT/M/2017 [8] on Building Facilities Requirements, evacuation facilities are a continuous and unobstructed path from any point in the building to the road, yard, field, or other open space that provides safe access to public roads. Every building except single dwelling houses and simple row houses must provide evacuation facilities needed especially during disasters or other emergency situations. This evacuation facility aims to provide an evacuation route for building users to get out of the building and to give access to evacuation officers, and consists of three main parts, namely 1) exit access; 2) exit; 3) exit discharge (see Figure 1).

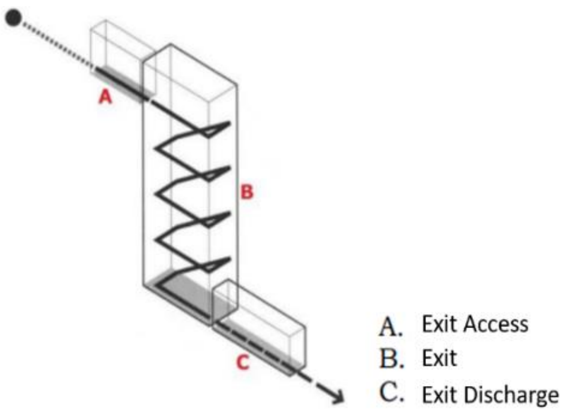

Figure 1. Evacuation route [8].

1.2 Wayfinding

Wayfinding can be defined as spatial problem solving by knowing where your location, destination, and how to get there from your present location [9]. Wayfinding is generally defined by Lynch (1960) [10] as the consistent use and organization of sensory cues derived from the external environment. Wayfinding is how a person moves from one location to another, encompassing the process of gathering information and making decisions to determine orientation and movement within a space whose design is based on research in cognition and environmental psychology to design spaces and products that facilitate the movement of people within urban environments and individual buildings [11]. Wayfinding and navigation are also described as encompassing the intentional movement through an environment and the thought processes that facilitate seamless travel between one place and another [12]. In its development, wayfinding is described as moving from one place to another, where the final destination may be back to the starting point [13], and is often perceived as the fastest or shortest route between two points [14-16] in [13].

From the definition above, wayfinding can be correlated with various verbs, such as moving and mobilizing. This underlies the wayfinding process in various contexts, such as ease of movement within a healthcare facility, ease of navigation in an airport or shopping mall, ease of reaching a destination in a tourist spot, and ease of reaching an evacuation route during a disaster. Similar to the concept of wayfinding, which is perceived as a route between two points, an evacuation path or route also shows two points, where the starting point is the point where a person is located, and the destination point is the assembly point as the destination location which is assumed to be a safe point. In a building setting, the starting point can be assumed to be a certain space, and the end point is a predetermined assembly point.

In the context of disasters, wayfinding related to the evacuation process becomes very important because this process is a process where people will jointly follow the flow of self-rescue, so various safety variables must be considered, one of which is the availability of evacuation routes that match the number of occupants of the building concerned.

2. Research Method

This research was carried out using case study method to choose to locus of the research. The research location is Masjid Syuhada Kindergarten or KB TK Masjid Syuhada located at Jl. I Dewa Nyoman Oka No.13, Kotabaru, Kec. Gondokusuman, Yogyakarta City, Yogyakarta Special Region 55224. This school was chosen as the research locus because it is one of the Disaster Preparedness Schools in Yogyakarta Special Region Province. This school is a school complex ranging from KB, TK, SD, to SMP, where Masjid Agung Syuhada is the center area. This school area is quite complex because it accommodates various groups of functions, and the KB TK area of Masjid Syuhada was chosen because of its location at the lowest point of this school complex area.

The data of children number was collected by interviewing teachers. Further, observation to construct school schematic plan was carried out in one day. The evacuation route and assembly points were also noted using school site plan from google images. For the research analysis, a deductive and quantitative method was implemented using Urban Netwok Analysis followed by descriptive explanation for the results.

KB TK Syuhada is an area of the school that is separated from the rest of the school because it is located below the main highway point. This area houses the KB, or Play Group, Kindergarten A, and Kindergarten B. The number of classes in each category and their occupancy is presented in Table 3. The KB TK area has a total of 10 classes, with a division of 3 KB classes, 3 TK A classes, and 4 TK B classes, where the total number of students is 171 and the total number of teachers is 20. It can be concluded that the total occupancy is 191 people.

Table 3. Class and occupancy

Class	Name	Students	Teachers
KB Play Group	KB1	7	2
	KB2	14	2
	KB3	11	2
TK A Kindergarten A	TKA1	20	2
	TKA2	18	2
	TKA3	17	2
TK B Kindergarten B	TKB1	20	2
	TKB2	22	2
	TKB3	20	2
	TKB4	22	2
Total	10	171	20

From this kindergarten area, there are 3 exit areas or assembly points connected by stairs, which in accordance with the definition of evacuation routes will be referred to as exit access or exit stairs. The location of the assembly points in relation to the overall school complex area can be seen in Figure 2. The assembly point area is generally also the meeting point between the kindergarten and primary school circulation. Although the kindergarten actually has a connection to the elementary school area where the elementary school area is right above the kindergarten building, but in general the access is closed, so that the circulation of the meeting between the kindergarten and elementary school will occur at two assembly points A and B. Assembly point A is the sports areas and assembly point B is the motorcycle parking area.

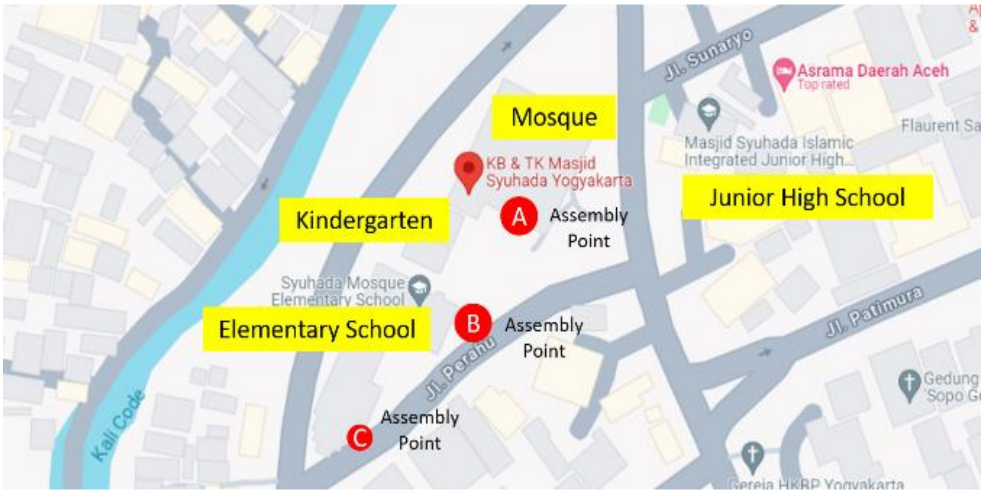

Figure 2. Location of the assembly point of the Masjid Syuhada Kindergarten KB

2.1 Urban Network Analysis

Urban Network Analysis (UNA) is an open-source toolbox launched by Sevtsuk of City Form Lab, which can be used to calculate five types of network centrality measures on spatial networks: Reach; Gravity Index; Betweenness; Closeness; and Straightness, where unlike previous network centrality tools that operate with two network elements (nodes and edges), the UNA tool includes a third network element - buildings - that can be used as the spatial unit of analysis for all measures [17]. In addition, the UNA tool also allows buildings to be weighted by specific characteristics in proportion to the analysis results, thus providing more accurate and reliable results for all specified measures. The UNA tool offers a reliable method for assessing distance, accessibility, and encounters between people or places along a spatial network [18].

This research utilizes the UNA toolbox in Rhinoceros 5 software which was developed to provide spatial network analysis tools for architects, designers, and planners who do not have access to GIS and typically design using Rhino. By having UNA metrics in Rhino, it not only allows one to analyse how a particular spatial network performs, but also incorporates the analysis into a rapid and iterative design process, where networks can be designed, evaluated, and redesigned in a seamless cycle to improve results quickly [19]. In its development, the analysis mode of UNA is increasing, including the closest facility analysis. Closest facility can infer how many origin points or origin point weights are closest to each facility in a set of facilities, and can optionally calculate gravity access values for those facilities [19].

3. Analysis and Discussion

In using the UNA tool, before conducting the analysis, the origin and destination points must be determined first. Based on Figure 3, which is a schematic plan of the KB area of Syuhada Kindergarten, the position of the classroom door and evacuation stairs or exit stairs can be seen. The position of the classroom door indicated by the orange circle will be determined as the origin point, while the point of climbing the exit stairs will be determined as the destination point. After determining the origin and destination points, determine the network in the form of paths or roads that may be passed by building users (see Figure 4). In adjustment for having two doors in one room, the origin points in class TKB1 and TKB3 are moved to the center of the room, assuming the network has passed through both doors. After going through the join, intersect, and split process. The UNA toolbox can be used to create a network for analysis. After the network is formed, each origin will be equipped with a weight or attribute number related to occupancy, and the analysis is carried out.

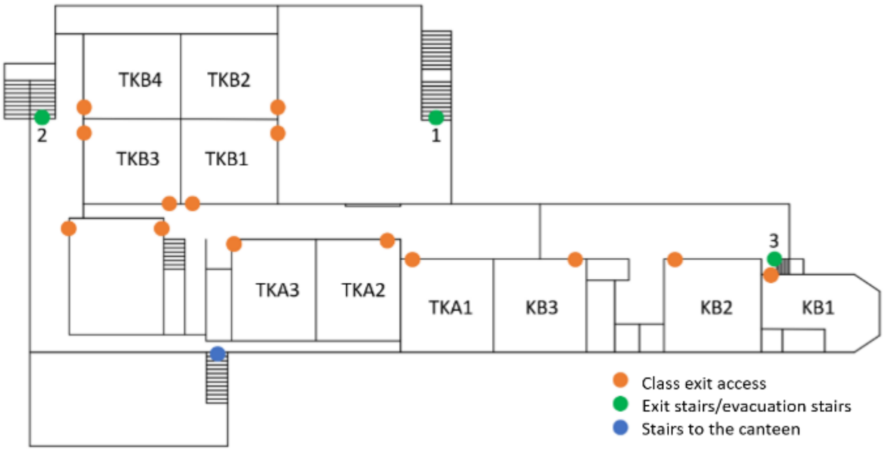

Figure 3. Schematic plan of the KB area of Syuhada Kindergarten

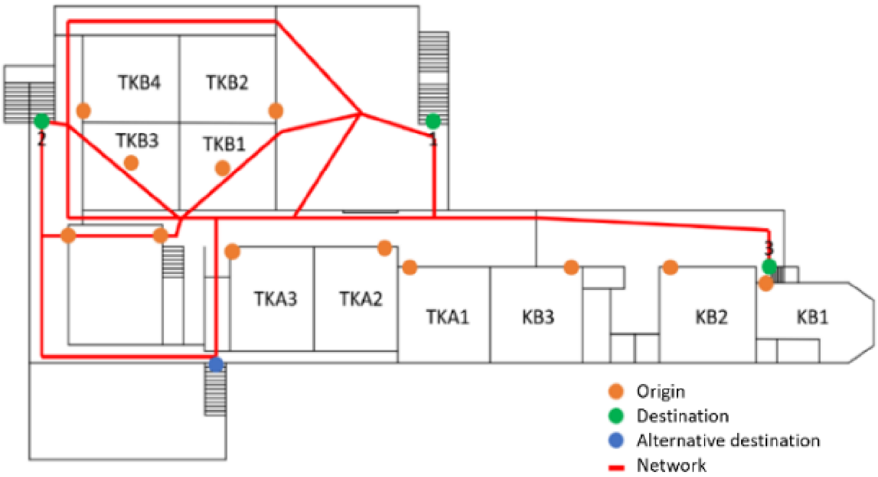

Figure 4. Schematic plan of KB TK Syuhada area for urban network analysis

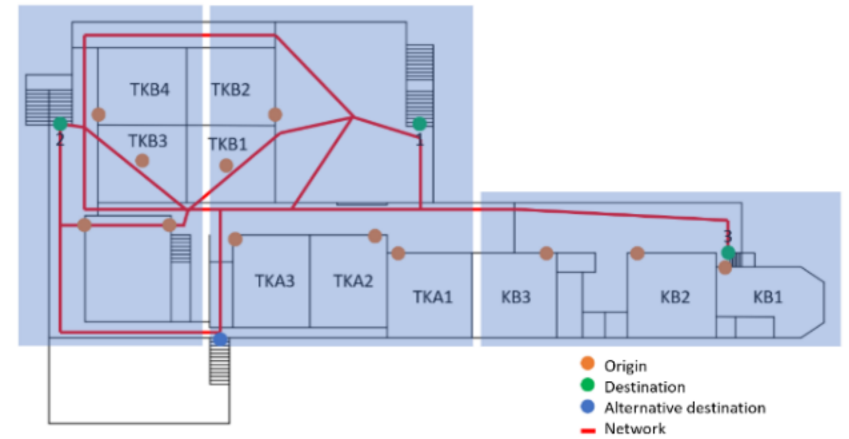

Figure 5. Evacuation zones before analysis

3.1 Closest Facility

As mentioned earlier, Closest facility can infer how many origin points or origin point weights are closest to each facility in a set of facilities, and can optionally calculate gravity access values for those facilities (City Form Lab, 2023). In relation to this research, Closest facility infers the destination point, or in this case the exit stair, that is closest to the classroom. This analysis can be used to answer the question: Are the exit stairs provided at Syuhada Kindergarten appropriate in terms of number, distance, and occupancy?

Before the analysis, the division of evacuation zones can be seen in Figure 5. Destination 1 is the destination of the origin points TKB1, TKB2, TKA1, TKA2, and TKA 3. On the other hand, Destination 2 is the destination of the origin points TKB3 and TKB 4. The last destination is Destination 3 which is the destination of KB1, KB2, and KB3.

The analysis with the Closest Facility tool is shown in Figure 5. After the analysis, from the origin point there is a blue line connected to the network. This line is a path line that shows how the origin is connected to the network that has been determined. Because the analysis asked for a connecting line to appear, a purple line was formed that connects the origin with the destination or the nearest exit staircase. From the analysis, exit staircase 1 was selected as the closest destination of 4 classes, namely classes TKA1, TKA2, TKB1, and TKB2. On the other hand, exit 2 was selected as the closest facility to 3 classes, namely TKB3, TKB4, and TKA3 classes, as well as a multipurpose room. Finally, the stairs of exit 3 were selected as the destination for the KB classes, from KB1 to KB3. Figure 6 shows the changes in evacuation zones based on the Closest Facility analysis results.

Table 4 shows the occupancy of each destination or exit staircase. The occupancy value shows the movement of the class occupancy towards the destination and the exit staircase 1 which is reached by 4 classes has the highest occupancy value of 88 people, which is almost 50% of the entire school occupancy (see Figure 7). It is followed by exit staircase 2 with an occupancy value of 65 people or 34% and exit staircase 3 with 38 people or 20%.

Table 4. Class and occupancy

Evacuation Zone	Class Name	Occupancy		Total
		Students	Teachers	
1	TKB1	20	2	88
	TKB2	22	2	
	TKA1	20	2	
	TKA2	18	2	
2	TKB3	20	2	65
	TKB4	22	2	
	TKA3	17	2	
3	KB1	7	2	38
	KB2	14	2	
	KB3	11	2	

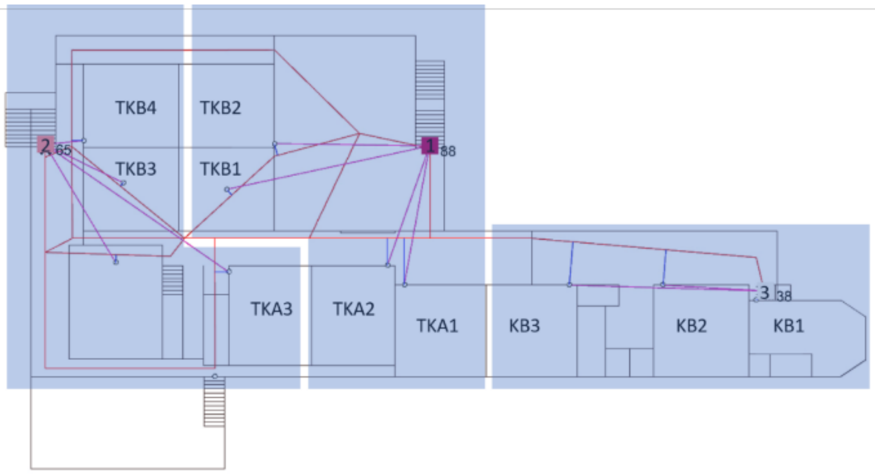

Figure 6. Analysis using the closest facility toolbox

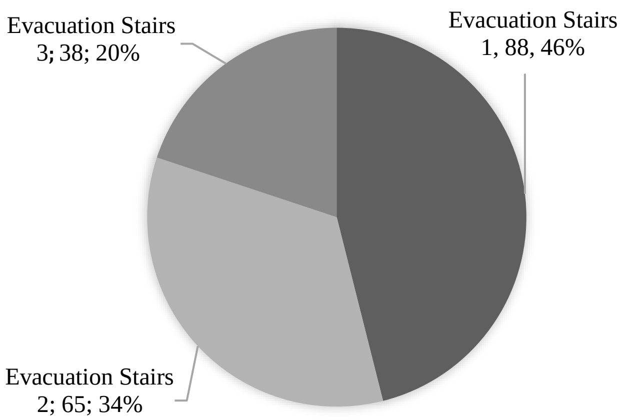

Figure 7. Percentage of occupancy of each destination to total school occupancy

The occupancy and number of evacuation routes in the form of exit stairs in buildings based on the Regulation of the Minister of Public Works and Public Housing of the Republic of Indonesia Number 14/PRT/M/2017 can be determined by the formula of occupancy load or total facility accommodation divided first by 15 as a divisor for exit stair facilities, then divided by n or the number of available exit stairs, which must be smaller or equal to 4. When the results obtained do not match, the value of n must be added. From the previous explanation, it can be determined that the occupancy load of Syuhada Kindergarten is 191 people and n is 3. The calculation in the formula (1) will be shown in the explanation below.

$$\frac{\text{Occupancy load}/15}{n} \leq 4 \qquad (1)$$

$$\frac{191/15}{3} \leq 4$$

$$\frac{12.7}{3} \leq 4$$

$$4.23 \leq 4$$

The calculation result is not in accordance with the provisions so ‘n’ must be added

$$\frac{191/15}{4} \leq 4$$

$$\frac{12.7}{4} \leq 4$$

$$3.175 \leq 4$$

There should be 4 exit stair facilities in the KB TK Syuhada facility.

Closest Facility analysis that shows the uneven distribution of occupancy of each exit stair and calculation analysis by formula shows that there is still a lack of the number of exit stairs in this Masjid Syuhada kindergarten facility. In Figure 5, there are alternative exit stairs or destinations that can be analysed using Closest Facility to determine whether the position of the exit stairs is suitable as an additional exit staircase at this facility.

Figure 8 shows that the alternative exit staircase 4 which is the access staircase to the cafeteria only has an occupancy value of 19 which is a divider of the exit staircase 2, although from the number of occupancies of each destination, it is assumed that the divider is the exit staircase 1 which has almost 50% occupancy. Therefore, the alternative exit staircase that is currently available at this KB TK Syuhada facility has not been able to fulfill the function as an exit staircase optimally.

4. Conclusions

Based on the Closest Facility analysis and the calculation formula for evacuation facilities in the PUPRI Ministerial Regulation Number 14/PRT/M/2017, the exit staircase facilities in the building of the Syuhada Mosque Kindergarten are still not optimal. In addition to the lack of the number of exit stairs which should be 4 points, the existence of alternative stairs in this facility cannot optimally accommodate the function as an exit staircase. In addition, from the closest facility analysis, it can be concluded that the distribution of occupancy at each destination or exit stairs is still uneven. The significant difference in occupancy will affect the standard width of the exit stairs and the travel time from the classroom, which still needs to be further analyzed to ensure its effectiveness, especially since the users of this evacuation facility are mostly children aged 3-7 years. The suggestion to the school is to review the addition of staircase exits in locations that allow more users to be accommodated to divide the dominant occupancy at one point.

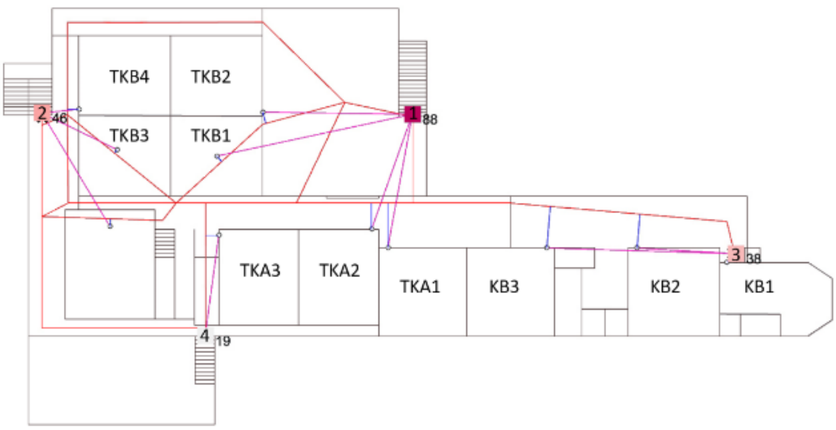

Figure 8. Analysis using the closest facility toolbox with alternative exit 4

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