Optimization of Firefighting Posts in Tabanan District

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Abstract

Tabanan is one of the districts in Bali which has ten sub-districts. The size of the site in Tabanan will affect the handling of fire incidents in each area in the Tabanan district. This handling relates to the response time of the fire brigade, who must be able to arrive at the location after 15 minutes from the received fire report. Travel time from the existing fire station to other remote districts will take more than 15 minutes. This is considered to result in delays in handling fire disasters—the impact of adding new firefighting posts in other sub-districts outside Tabanan District. However, setting up a fire station in every sub-district in Tabanan district will impact the costs that need to be incurred for constructing a fire station. Therefore, to overcome these problems, a location optimization method is required to provide aspects of the effectiveness of planning the establishment of a new fire station. The set covering problem can overcome this problem, providing the optimal number of fire stations by considering the distance traveled. This method will give results in the optimal number of fire stations that can cover all areas with a response time of 15 minutes. This study uses two-speed data obtained from interviews with the Tabanan districts Fire Department and speed data obtained from google maps. This study also uses the support of the QGIS application to determine the distance between sub-districts and uses the centroid point as the midpoint utilized to draw the line between the sub-districts.

Keywords: *Fire station, optimization, set covering problem, excel solver, QGIS*

INTRODUCTION

Indonesian people are often surprised by news in the mass media and electronically about fire incidents, especially in urban areas. The causes of fires are generally negligence in using daily items, short circuits in electrical equipment, and exploding stoves. In house buildings, fires will quickly spread to surrounding houses because the distance between places is minimal, there is almost no space, and the wind causes a high fire speed. This incident was experienced by a building shop owner at Jalan Tendean Number 90, Banjar Tanah Bang, Banyar Anyar Village, Kediri District, Tabanan, on Thursday, November 11, 2021, at 08.00 WITA. This fire incident was caused by an electrical short in the shop building, resulting in a spark that caused a fire. This fire spread to the shop area and caused Rp to lose 100,000,000.00 (Aryawan, 2021). Forest areas have the potential to experience fires other than the housing sector. The study of forest fires shows that the household sector is heavily affected by forest fires and can reduce the income of several industries (Ulya & Yunardy, 2006). The Tabanan city fire department only has one fire station located at the Fire Department, Delod Peken, Tabanan District, Tabanan district, Bali 82121. This becomes an obstacle

for firefighters if a fire occurs far from the fire station location. Meanwhile, according to the Regulation of the Minister of Home Affairs of the Republic of Indonesia Number 144 of 2018, firefighters have fifteen minutes to travel to the fire location as a response time.

Disaster hazards must be immediately anticipated and faced with various comprehensive, systematic, effective, and sustainable mitigation efforts. In the fire data obtained from the Tabanan district Fire Department in 2019-2022, there was an increase in material losses to the number of fatalities. In 2019-2022, two victims suffered burns. In 2020 four victims suffered burns. In 2022, one person died, and the 2nd-floor house caught fire and many others. The total loss in 2022 will reach IDR 920,000,000. In addition, forest fires have also occurred in Mount Batukaru, Tabanan, and Bali forests. The fire occurred on August 12, 2019. The fire managed to burn the land with 300 square meters. Handling has been carried out, but the BNPB Pusdalops (13/8/2019) still found embers at the fire site the next day (Yulika, 2019). One of the fire control efforts is setting the location of the fire station or post. This is closely related to the spread of fire. The faster the handling of firefighting personnel, the smaller the spread of the fire so that extinguishing efforts can be carried out by minimizing the impact. Similar to the fire incident experienced by the Tabanan Environmental Service. The fire can destroy within 30 minutes after the incident (Tabelak, 2017). However, it can still overcome it because the distance between the Tabanan Fire Department and the Environment Agency is quite close, only 1.8 kilometers, so fire events far from the Tabanan district Fire Department will have time constraints. Therefore, it is still a matter of concern for the government.

Mapping the location of the fire station as an emergency service facility requires special considerations in its development plan. So far, almost all urban areas in Indonesia do not yet have appropriate services for emergency conditions, both in terms of the number of facilities and mapping the location of fire stations as infrastructure. It is essential to research planning the mapping of the location of the fire brigade post by considering the various impacts or risks of loss caused by the fire disaster. This is also closely related to the existence of the term hazard, which must reduce in value. Hazard is another name for danger, where a hazard can be interpreted as a natural or artificial event that creates opportunities to threaten human life, both in terms of property and environmental impact (Rahman, 2018). One way to determine the location of firefighters' mapping can be done by utilizing technological advances. The technological advances used to help resolve this location are the QGIS application with a Geographic Information System (GIS). This application will determine the closest distance between points in an area.

The number of fire stations in Tabanan district is still considered not to be able to adequately cover its area, which has an area of 1,013.88 km². In addition, the situation was exacerbated by the condition of hydrants that could not operate in eight locations (NusaBali, 2015). The Government of Tabanan district should pay attention to adding new fire stations in areas that have not been or are difficult to reach by fire and rescue personnel. In planning the construction of a new fire station, we need to build a model that can determine where and how many new fire stations are.

This study aims to determine the optimal location and number of fire stations by considering time and distance aspects using a set covering problem model. The set covering problem model is used to analyze the coverage area of a facility where the coverage has a specific limit with the existing site boundaries; it is necessary to optimize it.

LITERATURE REVIEW

A. QGIS

One digital application that uses Geographic Information Systems (GIS) is the Quantum GIS or QGIS application, an open-source application. QGIS is an application with a Geographic Information System (GIS) that accommodates functions and features that allow users to be able to conduct a study of geographic data, to be able to make arrangements and compilations of existing maps. This QGIS application can run several operating systems on the user's device (Sukmono, 2016). One of the features accommodated by this QGIS application is the determination of the midpoint of an area called the centroid point. This centroid point will determine the shortest distance from each region.

B. Shortest Path

The shortest path, also known as the shortest path, is the smallest distance needed to reach the destination point. There are several types of problems that exist in determining the shortest path, where two of them are a pair shortest path or the minimum path in terms of the distance between two nodes and all pair shortest path or the minimum path in terms of the distance between several nodes (Mukti & Mulyono, 2018).

C. Solver Excel

Solver is a program in Microsoft Excel that can help troubleshoot problems. This solver program can solve issues regarding the minimum and maximum value in the optimization case. There are several processes in the excel solver: goal-seeking, unconstrained optimization, and constrained optimization.

D. Combination

In everyday life, determining an object's arrangement will use the concept of combination. This combination theory will be defined as an arrangement obtained by taking several elements from different things. In this combination theory, the resulting structure does not pay attention to the order (Warnars, 2006).

The calculation of this combination has been described through a mathematical formulation involving the object and the elements applied. Mathematically, the combination theory is formulated as follows.

$$_nC_r = \frac{n!}{r!(n-r)!}$$

C is the combination, n is the number of objects combined, and r is the element to be formed as a combination.

E. Optimization

Each activity certainly has a specific purpose as a result of the process. Optimization is the activity or treatment that gives the best results from a particular function in a situation (Zahrati et al., 2019). This optimization will be oriented to each activity so that each activity will expect optimization of the process results. Optimization can provide effectiveness and efficiency in everyday life from various aspects, such as cost, space, time, and others.

F. Set Covering Problem

Modeling a set covering area is closely related to optimization. The set covering problem can be used as a tool in the form of a mathematical method to achieve optimization. The set covering problem is a method that can use to optimize the establishment of a facility in a particular area, where the plan for the establishment of the facility will be oriented to the least amount (Idayani et al., 2020). A requirement will follow this minimum number that the minimum number of facilities in the area must be able to cover the entire site without exception.

G. Linear Speed

The term linear velocity plays a significant role in human life. Linear speed can be defined as the amount of distance something can travel in a specific time interval (Santoso et al., 2021). Speed results from the relationship between space and time, so there will be variables in the form of distance and time. The velocity equation formulated by mathematics will be a specific value as a speed measurement. The formulation of linear velocity is described as follows.

$$V = \frac{s}{t}$$

Where s is the distance traveled, v is the speed, and t is the time.

H. Google Maps

Google Maps is a free online map application that can use on Android, laptops or any communication device that supports the system. The google maps application is provided by Google and can be found on the playstore on Android devices. On the google maps site, we can see geographic data on almost any location on the earth's surface. The service of this application is interactive because, in the application, there is a map that can be shifted according to the user's wishes, change the zoom level, and change the appearance of the map. Google Maps also provides movable geographic map services and satellite maps for the whole world and travel routes. This application is made using several combinations of map images, databases, and interactive objects created with HTML, Javascript, and AJAX programming languages, as well as several other programming languages (Ardana & Saputra, 2016).

A geographic Information System (GIS) is created by using data that comes from processing some data, namely geographic data or data related to the location of objects on the earth's surface. GIS technology integrates database processing operations commonly used today, such as data collection based on needs, analyzing statistical data using visualizations with distinctive characteristics, and various advantages that geographical analysis can offer. Geographic Information Systems can also explain an event, make other strategic plans, forecast events, and help analyze a general problem (Sukmono, 2015).

RESEARCH METHOD

This study uses two types of data, namely primary data and secondary data. Primary data is information obtained directly by researchers to support research, and secondary data is obtained indirectly from the object under study, whereas secondary data is obtained from third parties (Helmi & Lutfi, 2014). One method of obtaining primary data is through direct interviews. Interviews were conducted to obtain factual data on all matters relating to the fire disaster in the

Tabanan district. The interview method was structured with the Field Coordinator at the Tabanan district Fire Department. In this study, a literature study was also carried out as secondary data acquisition in finding specific references to study theories related to linear programming, especially set covering problems and their application.

In addition, secondary data is in the form of data on the closest distance between sub-districts in Tabanan district, obtained from the QGIS application. Documentation techniques are implemented to acquire additional data that supports this research process. The data obtained include a track record of fire incidents in Tabanan district, average travel time from the nearest fire station to the sub-districts, and the average speed required for firefighting vehicles to reach the intended location. After that, as a follow-up output from the data that has been obtained, it is then inputted into the optimization model for determining the location and number of fire stations using the set covering problem model. Solving this problem will be done using the solver in excel. The following is the flow chart of this research.
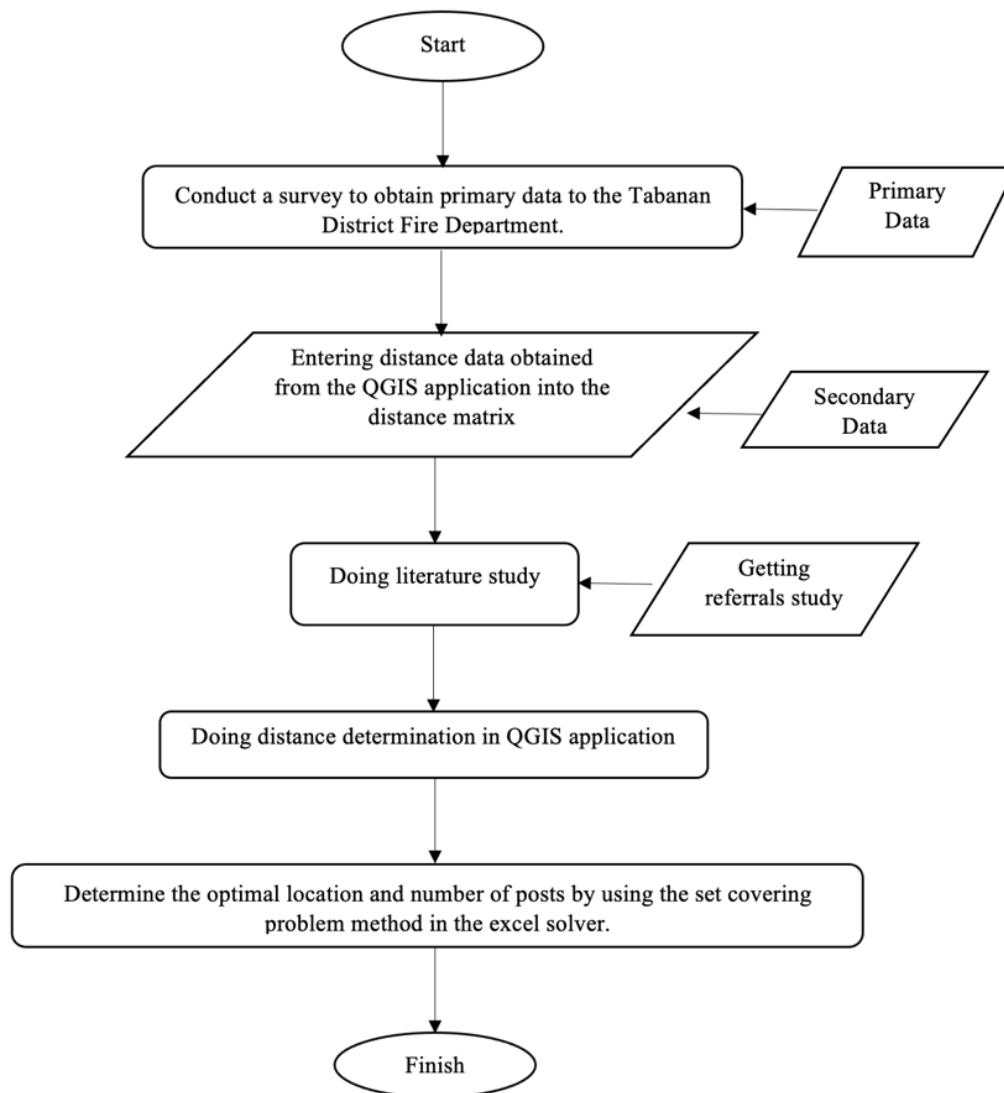
Figure 1. Flow Chart

The location of the research conducted is in the area of Tabanan district. The base locations used for research reviews are all sub-districts in the Tabanan district. First, the centroid point will make up the existing ten sub-districts. Then it is connected from one point to another in each sub-district. Furthermore, using the QGIS application will determine the shortest distance from each sub-district. The distance data will affect the determination of the location of the firefighter post. The following is a map of the sub-district administration in Tabanan district.
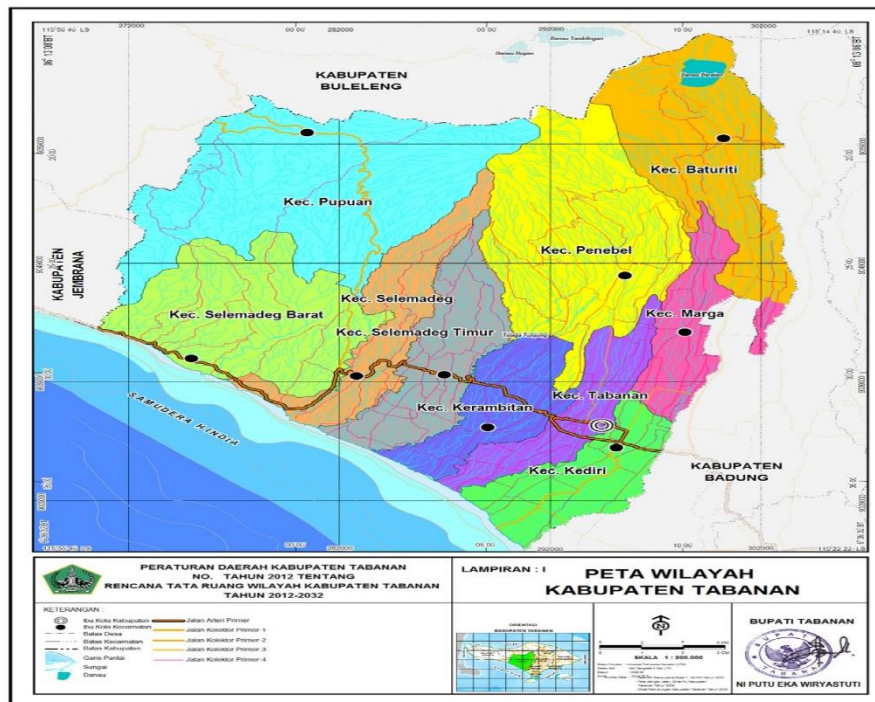

Figure 2. Map of the sub-district administration in Tabanan district.

FINDINGS AND DISCUSSION

In determining the location of this fire station, the QGIS application uses the value of the shortest distance from one sub-district to another sub-district in the Tabanan district. The first thing to do is to enter some files of type .shp into the QGIS application. The files include google maps, administrative maps of sub-districts in Tabanan district, and the existing road network. The second step is to bring up the centroid point in each sub-district area on the administrative map by pressing the vector selection at the top, selecting the geometry tool, and selecting the centroids. With this, the centroid point will appear in each sub-district area. After a centroid point exists, select the ORS equipment to determine the shortest distance from the two centroid points. To determine the shortest distance, set the ORS menu in the upper right corner, select the most temporary option, and click the plus sign. Thus, we will be able to draw a line from one centroid point to another centroid point. The last step is to click the "apply" option to bring up the shortest route ORS layer between the two sub-districts and rename the ORS layer according to the name of the partner district. As shown in Figure 2, we will look for the shortest distance between Penebel District and Pupuan District.
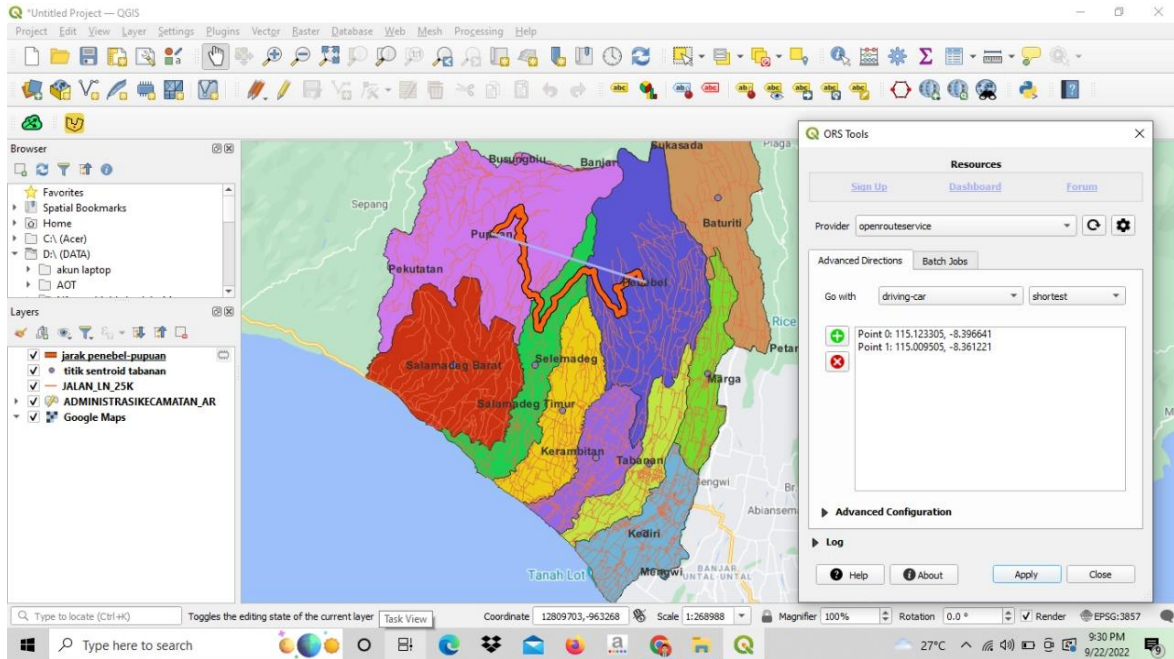
Figure 3. QGIS shortest route

After the shortest route appears between the sub-districts of penebel and pupuan, it will bring up the value of the closest distance to the road that has been determined. This is done by right-clicking on the ORS layer with the name "Penebel-Pupuan distance," selecting properties, and selecting "open Attribute Table." Then the closest distance value will appear, where in this experiment, the shortest distance from Penebel District to Pupuan District is 38.495 kilometers, as shown below.
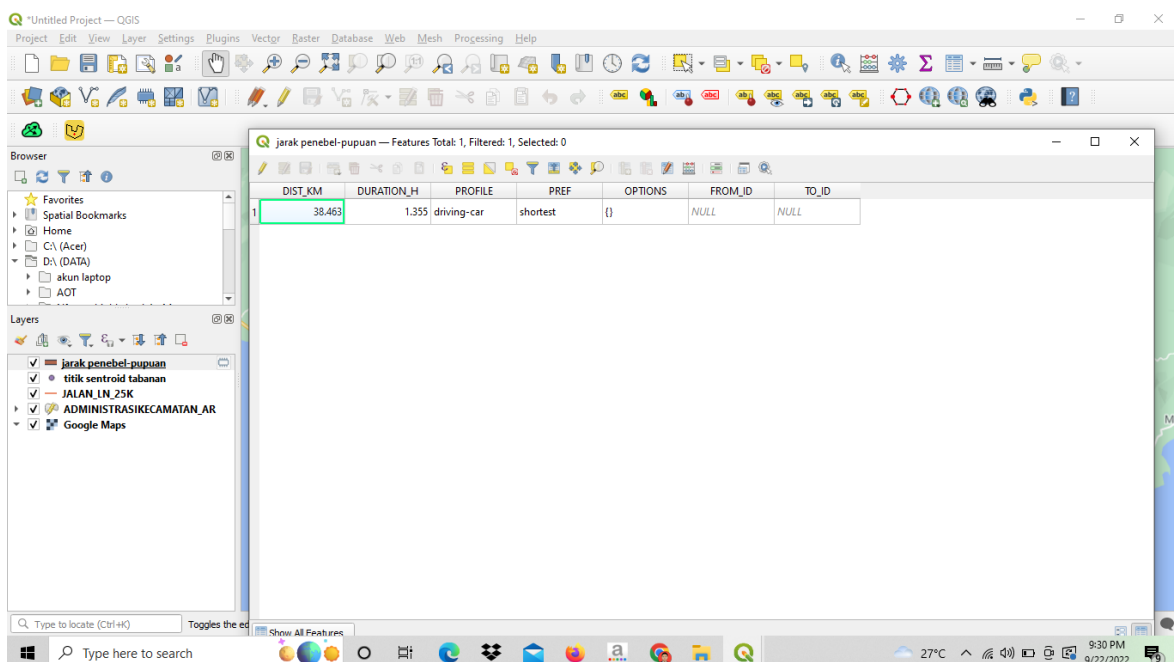
Figure 4. Route Distance Value Display

This step continues until all the distances between districts are obtained. After all the spaces between sections are Table received, the data is entered into the Table 1 below.

Table 1. Distance Matrix Between Sub-Districts in Tabanan

Jarak (Km)	Pupuan	Baturiti	Penebel	Marga	Salamadeg Barat	Salamadeg Timur	Salamadeg	Kerambitan	Tabanan	Kediri
Pupuan	0	43,191	38,495	42,83	35,104	27,337	22,407	34,221	38,051	44,223
Baturiti	43,191	0	19,643	15,994	51,338	31,675	37,311	19,874	26,883	31,268
Penebel	38,495	19,643	0	15,742	44,809	22,827	23,657	21,066	19,701	27,512
Marga	42,83	15,994	15,742	0	39,699	20,032	25,811	18,275	11,465	15,803
Salamadeg barat	35,104	51,338	44,809	39,699	0	24,312	20,916	26,992	31,107	31,479
Salamadeg timur	27,337	31,675	22,827	20,032	24,312	0	8,24	7,566	11,407	17,51
Salamadeg	22,407	37,311	23,657	25,811	20,916	8,24	0	13,5	17,387	23,447
Kerambitan	34,221	19,874	21,066	18,275	26,992	7,566	13,5	0	8,178	12,137
Tabanan	38,051	26,883	19,701	11,465	31,107	11,407	17,387	8,178	0	9,019
Kediri	44,223	31,268	27,512	15,803	31,479	17,51	23,447	12,137	9,019	0

The data above is the distance data between sub-districts in the Tabanan district. The data is obtained through the QGIS application by finding the shortest distance from each sub-district in the Tabanan district. Based on these data, it can be seen that there are numbers that vary from the space between districts. This distance difference is quite significant, where the distance is not far from one sub-district to another. However, several sub-districts are far from other districts. This difference in space will affect the timeliness of firefighting services. Punctuality in firefighting services follows the applicable Regulation of the Minister of Home Affairs of the Republic of Indonesia Number 114 of 2018, which states that the preparation time to travel time from the fire department to the point where the fire is located as a response time is fifteen minutes. However, based on data obtained from interviews conducted at the Tabanan Fire Department with resource persons, the fire brigade used to extinguish fires at the location was first prepared by the fire brigade in terms of operators and the equipment needed later. This can provide information that can allocate a response time of fifteen minutes in its entirety to travel time.

The provision of this response time will impact the distance and speed of the car. Referring to the data obtained based on interviews at the Fire Department, the rate of the fire engine ranges from 60 km/hour to 90 km/hour. Therefore, we took the lowest speed, namely the speed of 60 km/hour. We chose the rate with a magnitude of 60 kilometers/hour because with a minimum speed of 60 kilometers/hour; one can still travel a busy road while still paying attention to the 15-minute time, so with the above rate, of course, the fire engine will be able to cover the distance, which is further away. The calculation between space, speed, and time variables can produce the maximum length that a fire engine can travel for 15 minutes.

Table 2. Solver Results with A Speed Of 60 Km/Hour

	Pupuan	Baturiti	Penebel	Marga	Salamadeg barat	Salamadeg timur	Salamadeg	Kerambitan	Tabanan	Kediri			
select	1	1	1	0	1	1	0	0	1	0	6		
Pupuan	1	0	0	0	0	0	0	0	0	0	1	≥	1
Baturiti	0	1	0	0	0	0	0	0	0	0	1	≥	1
Penebel	0	0	1	0	0	0	0	0	0	0	1	≥	1
Marga	0	0	0	1	0	0	0	0	1	0	1	≥	1
Salamadeg barat	0	0	0	0	1	0	0	0	0	0	1	≥	1
Salamadeg timur	0	0	0	0	0	1	1	1	1	0	2	≥	1
Salamadeg	0	0	0	0	0	1	1	1	0	0	1	≥	1
Kerambitan	0	0	0	0	0	1	1	1	1	1	2	≥	1
Tabanan	0	0	0	1	0	1	0	1	1	1	2	≥	1
Kediri	0	0	0	0	0	0	0	1	1	1	1	≥	1
									=				
									1				

The Table 2 above shows the results obtained after performing a series of operations using the solver in excel can explain that in the table above, the zeros and ones in the distance matrix have a special meaning. The zeros and ones in the column indicate the truth and error values against the pre-defined requirements as the program objective. In this case, previously presented the distance matrix between one sub-district and another. The distance between these districts is different from one another. Therefore, one must determine the maximum distance a fire car can travel at 60 km/h in 15 minutes. By using the linear velocity formula, the space that can cover in 15 minutes at a rate of 80 km/hour is

S max = 60 km/hour x 15 minutes
      = 60 km/hour x 0.25 hour
      = 15 km

Fifteen kilometers is the maximum distance a fire engine can travel for 15 minutes. A comparison will be made between the distance from each sub-district with a value of 15 kilometers as the maximum distance traveled. Corresponds to the binary numbers in the following table. If the comparison results show that the maximum distance traveled, 15 kilometers, is greater than the distance between sub-districts, then the value in that column will be accurate. However, if the distance between sub-districts is greater than the maximum distance traveled as a result of the comparison, then the requirements of the function are not met, and the value is false, which in turn will result in a zero value.

The value of one at the bottom of the Tabanan column colored in green indicates that there are fire extinguishing facilities in Tabanan District. After the solver has been carried out by entering several conditions, it is obtained that the number of locations for firefighting post facilities is saved by considering that all sub-districts in Tabanan district can still be covered. The solver process results found six strategic locations to establish firefighting post facilities marked with the number one with a red column. The sub-districts are Pupuan District, Baturiti District, Penebel District, West Selemadeg District, East Selemadeg District, and Tabanan District. Because there are fire extinguishing facilities in Tabanan District, then it is only necessary to build five more firefighting facilities to cover all sub-districts in Tabanan district within 15 minutes at a speed of 60 km/hour.

The speed used as a basis is not only based on interview data. In this study, we also use the rate we calculate based on the average speed on google maps. We connect the points in each sub-district, so we get the distance between the sub-districts and the travel time. With that, the speed

needed to cover the distance between districts can be calculated if taken by car using the average rate. The following is the speed matrix between sub-districts in the Tabanan district.

Table 3. Speed matrix based on google maps (km/h)

Matriks Kecepatan Berdasarkan Google Maps (Kilometer/Jam)									
	Pupuan	Baturiti	Penebel	Marga	Salamadeg barat	Salamadeg timur	Salamadeg	Kerambitan	Tabanan	Kediri
Pupuan	0	31,3	36,4	34,18	39,44	36,52	38,53	35,31	34,75	34,38
Baturiti	31,3	0	33,62	42,3	34,1	33,98	33,91	35,15	37,82	38,49
Penebel	36,4	33,62	0	33,25	32,78	30,95	31,38	28,6	32,38	31,54
Marga	34,18	42,3	33,25	0	32,1	30,35	29,88	29,43	27,41	27,73
Salamadeg barat	39,44	34,1	32,78	32,1	0	30,32	30,81	30,36	29,18	29,31
Salamadeg timur	36,52	33,98	30,95	30,35	30,32	0	33,64	28,67	27,5	27,75
Salamadeg	38,53	33,91	31,38	29,88	30,81	33,64	0	28,75	28,42	28,5
Kerambitan	35,31	35,15	28,6	29,43	30,36	28,67	28,75	0	27,9	28,8
Tabanan	34,75	37,82	32,38	27,41	29,18	27,5	28,42	27,9	0	26,7
Kediri	34,38	38,49	31,54	27,73	29,31	27,75	28,5	28,8	26,7	0

To obtain one speed as a reference to find the maximum distance traveled, then from the distance matrix, we can take the average speed. The average rate can calculate by dividing the total number of speed quantities connecting the sub-districts by the number of pairs connecting the two sub-districts. The number of teams between sub-districts can calculate using the combination formula. Because ten sub-districts will only connect two sub-districts, the value of n is ten, and the importance of r is two. Then the calculation is carried out as follows.

10C2=10!/(2!(10-2)!)
     =10!/2!8!
     =45

So, the number of pairs of sub-districts that connect two sub-districts from ten existing sub-districts is 45 pairs, following the calculation of the average speed from the speed matrix obtained from Google Maps.

Average speed = (total sum of speed quantities connecting between sub-districts)/(number of
          pairs connecting two sub-districts)
          = (1.444.57)/45
          =32.1 kilometers/hour

After knowing that the average speed using google maps is 32.1 kilometers/hour, it will use that speed to find the maximum distance that can travel in 15 minutes. Calculations are carried out as follows.

S max = 32.1 km/hour x 15 minutes
      = 32.1 km/hour x 0.25 hour
      =8,025km

Table 4. Results Of Solver with A Speed Of 32.1 Km/Hour

	Pupuan	Baturiti	Penebel	Marga	Salamadeg barat	Salamadeg timur	Salamadeg	Kerambitan	Tabanan	Kediri			
select	1	1	1	1	1	1	1	0	1	1	9		
Pupuan	1	0	0	0	0	0	0	0	0	0	1	≥	1
Baturiti	0	1	0	0	0	0	0	0	0	0	1	≥	1
Penebel	0	0	1	0	0	0	0	0	0	0	1	≥	1
Marga	0	0	0	1	0	0	0	0	0	0	1	≥	1
Salamadeg barat	0	0	0	0	1	0	0	0	0	0	1	≥	1
Salamadeg timur	0	0	0	0	0	1	0	1	0	0	1	≥	1
Salamadeg	0	0	0	0	0	0	1	0	0	0	1	≥	1
Kerambitan	0	0	0	0	0	1	0	1	0	0	1	≥	1
Tabanan	0	0	0	0	0	0	0	0	1	0	1	≥	1
Kediri	0	0	0	0	0	0	0	0	0	1	1	≥	1
									=				
									1				

After calculating through the solver in excel, the result that a total of 9 firefighter posts must be built in several sub-districts, namely Pupuan District, Baturiti District, Penebel District, Marga District, West Selemadeg District, East Selemadeg District, Selemadeg District, Tabanan District, and Kediri District. However, in this case, in the Tabanan sub-district, a fire station has been built, so that postal development planning will be carried out in 8 other selected sub-districts using the coverage area method in the solver in excel.

From the two speeds used, namely the minimum speed according to the informant and the average velocity obtained from google maps, which are 60 km/hour and 32.1 km/hour, respectively, it can be seen that there are differences related to the number of plans for the construction of fire stations, which can cover all sub-districts in Tabanan district.

CONCLUSION & FURTHER RESEARCH

The optimization of the location in the sub-district in Tabanan district is based on data from sources that state that the minimum speed that can travel in crowded conditions is 60 kilometers/hour, so we get a solution that it takes six fire stations to be built. The six locations are Pupuan District, Baturiti District, Penebel District, West Selemadeg District, East Selemadeg District, and Tabanan District. This amount is the most minimal, so if the construction of the fire station is carried out, it will be able to save costs. The coverage area system selected six areas, which cover other sub-districts with a maximum distance of 15 kilometers from the point of establishment of the fire station. Requires that the speed of the fire engine cover the distance at a speed of 60 km/h in 15 minutes. If the fire engine's speed can be more than 60 km/hour, then the distance covered in 15 minutes will be even longer because the Tabanan District has established a fire station managed by the Tabanan Fire Department. The plan to build a fire station will only occur at five locations: Pupuan District, Baturiti District, Penebel District, West Selemadeg District, and East Selemadeg District. Location optimization is carried out with an easy method through several applications, such as using a solver in excel with the coverage area method and using QGIS to find the closest distance between sub-districts in Tabanan district.

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