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MATHEMATICS SPATIAL ANALYSIS FOR OPTIMIZATION THE FIRE FIGHTING STATION PLACEMENT IN SOUTH JAKARTA, INDONESIA

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ABSTRACT

This research aims to apply the spatial analysis to optimize the placement of firefighting units in the area of South Jakarta. The calculation and pre-analysis shown that there are some uncovered service areas at South Jakarta. Therefore, the recalculation and analysis help to find out the strategic new possible location for the fire station. Optimalization of the location of the new fire station is conducted by calculating the minimum time travel from help point to fire point. Other than that, the minimum time travel also calculated based on actual blocks and crowd. After that, the optimizing the location of the fire unit is determined by the support of a planning tool known as ArcView. It is a Geographic Information System (GIS) through the formulation of a mathematical and accessibility model. Through the new analysis with considering the actual fact and using the technology, the results showed that to optimize of the entire range of the South Jakarta area another ten new posts of firefighting unit need to be added.

Keywords: Accessibility, spatial analysis, the fire department.

ABSTRAK

Tujuan dari penelitian ini adalah untuk menerapkan analisis spasial untuk optimalisasi penempatan unit pemadam kebakaran di wilayah Jakarta Selatan. Perhitungan dan analisis awal menunjukkan bahwa terdapat beberapa area yang tidak terjangkau area pelayanan. Oleh karena itu, perhitungan ulang dan analisis dilakukan Kembali untuk menentukan lokasi baru yang memungkinkan untuk pos pemadam kebakaran. Optimalisasi lokasi dilakukan dengan memperhitungkan waktu tempuh minimum dari titik bantuan ke titik kebakaran. Selain itu juga dikalkukasi waktu tempuh berdasarkan hambatan. Kemudian optimalisasi lokasi pos unit pemadam kebakaran diperkuat dengan analisis menggunakan dukungan alat perencanaan yang dikenal sebagai arcview. Alat ini merupakan Sistem Informasi Geografi (GIS) melalui model rumusan matematis dan aksesibilitas. Hasil penelitian menunjukkan bahwa untuk optimalisasi jangkauan seluruh daerah wilayah Jakarta Selatan perlu ditambahkan lagi sepuluh pos unit pemadam kebakaran yang baru.

Kata kunci: Aksesibilitas, analisis spasial, pemadam kebakaran

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INTRODUCTION

The majority of South Jakarta resident are employer at the Central Jakarta area, where the center of government and economy is located. Most fire incidents occurred in residential buildings (Xin & Huang, 2014). Building fires are seen to pose a serious risk to human safety and are typically brought on by human action (Shokouh et al., 2019). Electrical failures and improperly fire use in daily life were major causes of fire incidents (Xin & Huang, 2014). Most South Jakartan resident leave their homes from dawn to evening as a result of this reality. The possibility of a fire is even greater when the homeowner forgets to turn off the stove or there is a short circuit in the electricity supply in the house. The amount of fire risk in a region is strongly influenced by seasonal and environmental conditions. Most areas of South Jakarta are populated by people with low levels of education. These people tends to use the unsafe and potentially hazardous electricity (Francioli, 2018).So that many house buildings are less safe against the threat of fire and slum environments that accelerate the spread of fires (Irwansyah et al., 2011)

The fire incidents often occur at South Jakarta. In August 2020, in total there are 21 fire incidents in the South Jakarta Area (Tristanto, 2020)). This data add by the current situation that in between two week on August 2022, there are two big fire incidents at Simprug Golf Area and Setiabudi (Alfons, 2022)There are dozens of fire truck tried to extinguish the fire, and mostly it took more than 15 minutes for the fire truck to reach the area(Murti, 2022) By looking at its uniqueness, South Jakarta area is used as a sample in this research.

Problems arise when the need for fire disaster management cannot meet the needs in the South Jakarta area. Dealing with fire problems requires accuracy and speed, but there are many issues that prevent firefighters from providing the best possible service, including difficult access to certain areas, a lack of infrastructure for extinguishing fires, fires that are located far from the posts of firefighters, obstacles brought on by traffic, and so on (Nuranti, 2016)). The location of firefighting facilities needs to be optimized, hence research is required to look into this. In order to provide the best service, don't minimize the necessity to relocate nearby facilities or add firefighting equipment in hard-to-reach areas that are prone to flames. This paper discusses the optimization of the placement of firefighting facilities in South Jakarta using spatial analysis methods and the use of computer programs to help solve these problems. Similar to that, this analysis assumes uniform traffic conditions across the municipality. There is no accumulation of vehicles or road closures and roads are under controlled conditions and fire engines have top priority on traffic so that when traffic jams occur, fire engines can keep moving.

METHOD

In order to solve the problem above, several mathematical models are applied. The mathematical model used to find the maximum travel time has important elements such as time (t), distance (d), delay time or obstacle/load (r) and average speed (v). In the basic physics formula for distance is

$$t = \frac{d}{v} \tag{1}$$

Events in the field demonstrate a relationship between time and obstacles: the longer the time, the larger the loads or obstacles. In order to determine the maximum travel time, each trip's load or delay is given. An empirical formula derived from the "BPR (Bureau of Public Roads) Formula" is used to compute the delay time (FHWA 2001) as follow(Haris, 2011)

$$t_{\max} = t_f \left(1 + 0{,}84 \left(\frac{V}{C} \right)^{5,5} \right) \tag{2}$$

with
$V = 1{,}3C$ and C = 80% road based capacity.
$t_{\max}$: maximum time per trip ; t_f : hassle-free travel time
C : practice road capacity; V : road user volume

Road capacity is the ability of a road segment to accommodate the ideal traffic flow or volume in a certain time unit, expressed in the number of vehicles that pass certain road sections in one hour (vehicles/hour). According to wikipedia Indonesia, the capacity of roads in the city = 2300 passenger cars per hour

Therefore, the practice road capacity can be calculated as $C = \frac{80}{100} \times 2300 = 1.840$. The practice road capacity is 1.840 cars per hour. Other than that, the road user volume is calculated as $V = 1{,}3 \times 1.840 = 2.392$. By the calculation, the road user volume is 2.392 cars per hour. Therefore, the delay time can be calculated using formula (3ingg) as follow

$$t_{\max} = t_f \left(1 + 0{,}84 \left(\frac{2.392}{1840} \right)^{5,5} \right) = 2{,}1949 t_f \tag{3}$$

with t_f : hassle-free travel time

Midpoint of Coverage Area

The aspects to calculated the midpoint of area are consist with the points coordinate of the area (x_m, y_m), help point coordinate (x_r, y_r), and the number of choosen points (N). In order to calculate the mipoint area, the formula of center point of gravity can be used as follow

$$titik.pusat = \frac{\sum jarak.titik_{ab} \times berat.titik_a}{banyak.titik_b} \tag{4}$$

Since the area to be searched for the center point has a small scope of variance, it is assumed that the point weight at all points is the same (Wilson, 2000)

$$titik.pusat = \frac{\sum jarak.titik_{ab}}{banyak.titik_b} \tag{5}$$

Without the midpoint, formula 5 can be used for distance average of every point in the distric with the help point coordinate is located outside the district. Therefore the formula can be derived as follow:

$$\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t(x_m, y_m \mid x_r, y_r) \tag{6}$$

Based on the mathematics model used, the steps for implementation is conducted as follow (Câmara et al., 2010; Hansen, 1959)

1. Design the geographic network for the optimum location of the fire station and calculate the minimum service time between two points, and then a matrix of minimum service time and minimum reach time can be determined as T_{ij}.
2. Evaluate the condition of the capacity of the fire station, which can be seen in the postal service area by using the maximum service time of service time. Maximum service time can also be used to see if the service can handle the entire surrounding area. If it can serve the entire area then the point can be used.
3. Find the number of new possible fire station p based on the service graph used.
4. Calculate the midpoint of each service area based on the geographic network, and then determine the service area.
5. If the new calculation cannot cover all the area, then the location of new possible fire station should be re-evaluated and relocated so that it is able to cover all area.

6. Determine the location of new possible fire station with the detention condition. $d_{jk} \geq d_0$ (the distance between the fire station and the location of public facilities is greater than 50 meters). If all the condition fullfiled, the location of new possible fire station is at the optimum. The detail and omplete can be seen from the Figure 1**.** (Stairwell, 2014)

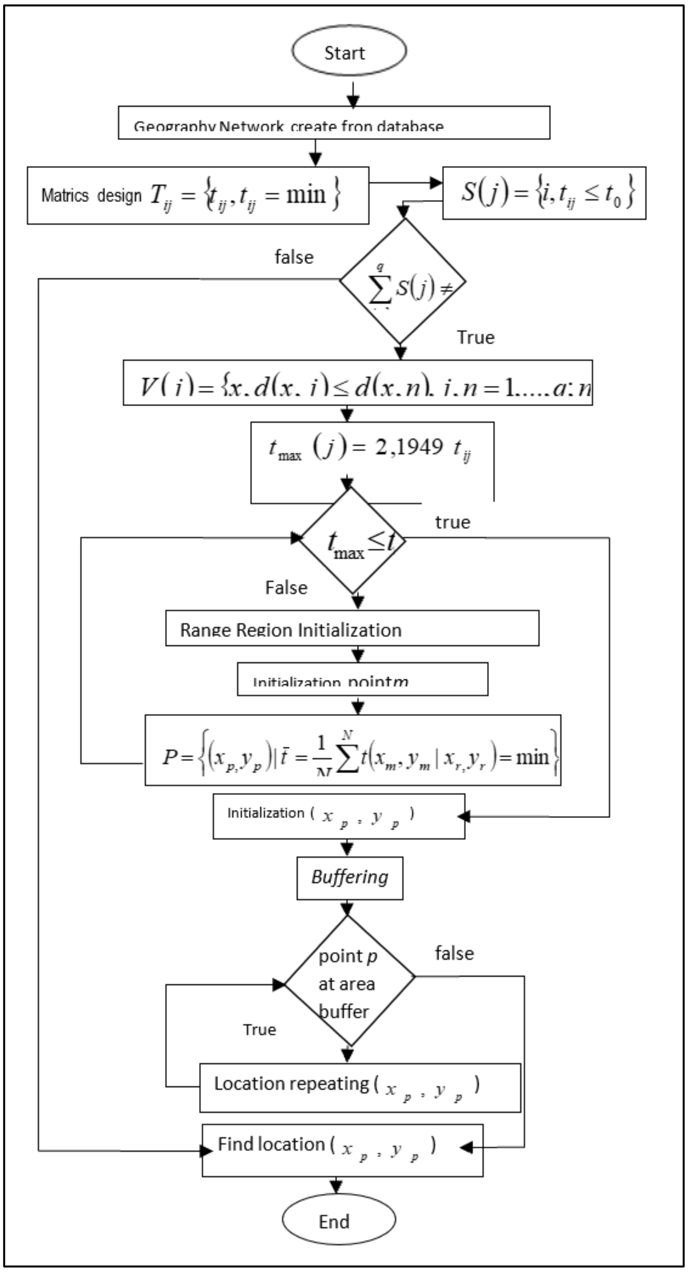

Figure 1. Flowchart Spatial Analysis Process

RESULT AND DISCUSSION

The research is conducted in the South Jakarta area with the location of fire station as the observation objects. After the spatial data is available, matrix T_{ij} is designed with considering the calculation of help point *i* to need point *j*.The need point is assumed as the fire-prone point such us the crossroad in the geographic network. It can be seen from Figure 2, three pink points (help point Casablanca, help point Mampang, and help point Tebet) are three help point i and green points are the need points j. With the help of the program, the minimum time travel to all the nearest help points to need points can be determined.

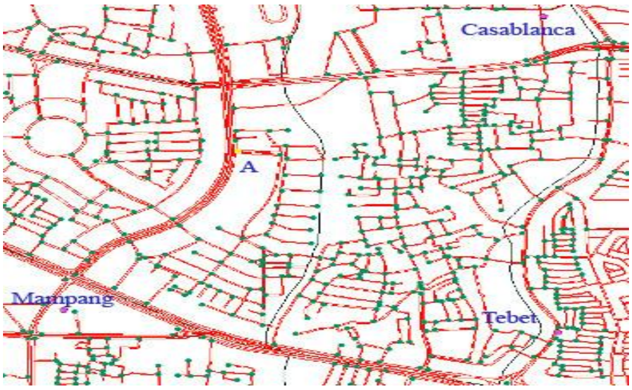

Figure 2. Determine the Matrix T_{ij}

The example case for this is explained as follow. In determining the minimum time travel between need point j and help point *i*, took a point A (yellow point) which assumed as the need point. In order to determine the minimum time travel between point A to three help poins with assumptions that the average speed of car is 50 kilometres per hour is calculated as follow.

Distance between point A to help point Mampang is 1.302 kilometres. Therefore

$$T_{AM} = \frac{1{,}302}{50} \times 60 = 1{,}5624 \tag{7}$$

The minimum time travel from point A to help point Mampang is 1 minute 6 seconds.

The distance between point A to help point Tebet is 3.325 kilometres. Therefore

$$T_{AT} = \frac{3{,}325}{50} \times 60 = 3{,}99 \tag{8}$$

The minimum time travel between point A to help point Tebet is 4 minutes.

One more, for the distance between point A to help point Casablanca is 1.994 kilometres. Therefore

$$T_{AC} = \frac{1{,}994}{50} \times 60 = 2{,}3928 \tag{9}$$

The minimum time travel for pont A to help point Casablanca is 2 minutes and 4 seconds.

Matrix T_{ij} from the need points in the formula 7, 8, 9 can be derived as follow

$$T_{Aj} = \begin{bmatrix} 1{,}5624 \\ 3{,}99 \\ 2{,}3928 \end{bmatrix} \tag{10}$$

After that, it can be determined that the need point A will be served by help point Mampang with the minimum time travel is 1 minutes and 6 seconds. The equations is

$$S(j) = \{i, t_{ij} \le t_0\} \tag{11}$$

$S(j)$ is the set collections of need points j with the value t_{ij} lesser than t_0. t_0 is assumed as the maximum time travel allowed in every travel. The maximum time travel from need points j to help point i is assumed to maximum 10 minutes. The assumption is taken based on the actual data of maximum time travel allowed in the fire fighter system in South Jakarta t_0 = 10 menit.

All the green points that is located in the crossroad in the network geography in the figure has value t_{ij} that is lesser than t_0 . Therefore all the green points are part of the service area of help point i. After that, comparation is conducted between the number of member $S(j)$ from all available help points i with *n* (the number all need points j). The equation is derived as: (Papoulis & Pillai, 2002)

$$\sum_{j=1}^{19} S(j) \neq n \tag{12}$$

If all the number of member $S(j)$ is lesser than the number of need points j, it means that there are some of need points j which is not served by the nearest help point i . therefore, the mapping is conducted for all service area i.

In order to represent the real condition of the main road, the time travel from each help point *i* to need point *j* is given a delay time so that the maximum time travel for each trip can become more accurate. To simulate the maximum time travel $t_{\max}$ to all need point j if traffic or other block happen can be done by multiplying the coeeficient of delay time to the time travel of fire truck to reach the help point. The calculation of the maximum time travel can be derived as the following equation

$$t_{\max} = 2{,}1949 t_f \tag{13}$$

From the calculation of Equation (12) where the need point A is serve by help point Mampang which has the minimum time travel 1 minutes and 6 seconds, the delay time can happened during the trip can be derived from Equation (13). Therefore, the maximum time travel of help point Mampang to need point A with blocks/traffic is

$$t_{\max} = 2{,}1949 \times 1{,}5624 = 3{,}4293 \tag{14}$$

Based on the calculation, the maximum time travel of help point Mampang to need point A is 3 minutes and 4 seconds.

$$t_{\max} \le t_0 \tag{15}$$

The calculation of maximum time travel of each help points *i* to need point *j* which did not exceed 10 minutes will be mapped into area diagram of all help point *i*. In the figure 3, each mid-point of polygon is the help point i and all the area inside the polygon are the serve area of help point i. After the mapping done, it can be seen that there are several areas that did not get the service from the nearest help point i. Therefore, the urgency to look for the newest possible help point is necessary.

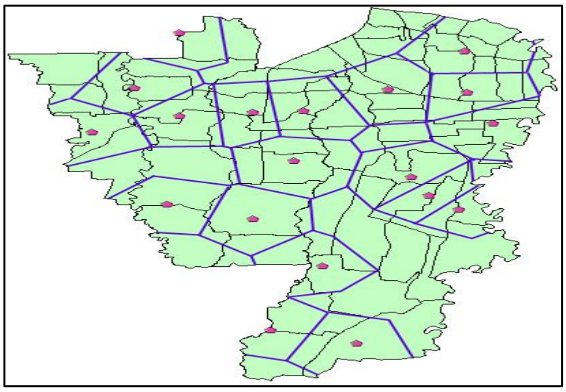

Figure 3. The service area diagram of help points

For all the need point which has $t_{\max}$ value greater than 10 minutes, will be called as point m. In figure 4, it can be seen that the collection of point m creates a polygon area which each points inside it cannot be served by the nearest help points. In order to locate the newest possible help point, the midpoint of each polygon is determined.

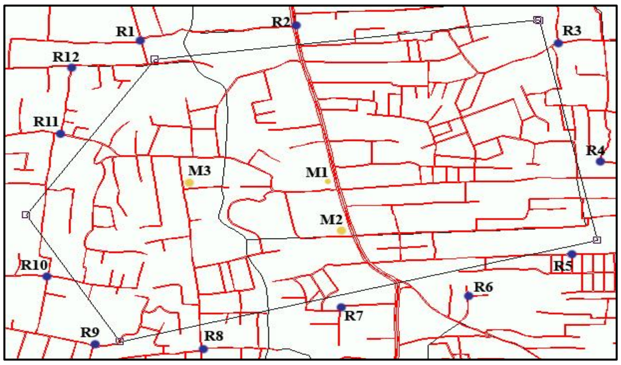

Figure 4. Determination the midpoint of points m area

The symbols R1-R12 indicate the closest points outside the polygon which will be potential locations for firefighters posts. Furthermore, the symbols M1-M3 denote the necessary m points discussed above.

The next step is to determine several nearest points outside the polygon. It is indicated as point r, as can be seen on Figure 4. Each of the points inside the polygone has $\bar{t}$ value which is the average time travel between the point m with point r. The average value can be derived using the following equation (QShen, 1997)

$$\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t(x_m, y_m \mid x_r, y_r) \tag{16}$$

In Figure 4, 12 points is determined and those points then indicated as points r. The calculation to find the midpoint of each polygon which did not get the service from the nearest help point j can be determined using Equation (16)

Table 1. Calculation to find the smallest $\bar{t}$

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	t
M1	995	737	1056	1013	944	676	533	869	1164	1174	1088	1158	951
M2	1182	936	1150	999	839	504	341	769	1104	1186	1200	1311	960
M3	667	826	1572	1604	1508	1174	804	694	773	637	518	688	955

After all the calculations and comparitions of all point m inside the polygon, the newest possible help points is determined in each of the polygon. After that, the re-observation is conducted to make sure that all the need points j are located inside the service area of help points i. If all the need points is reachable by the help points, then all the new help points p has to be located 50 meters away from the centre of crowd or public facilities. With the help of geography arcview, the location of new help points can be easily compared to the buffer of crowd such us mall, market, schools, and other public facilities. After that, the final check is conducted to make confirm that the new help poin P is not located near by the crowds. If it is confirmed, then the new help poin P will become the new locations of the fire station. In the Figure 5, the green square box are indicated the new locations of the fire stations.

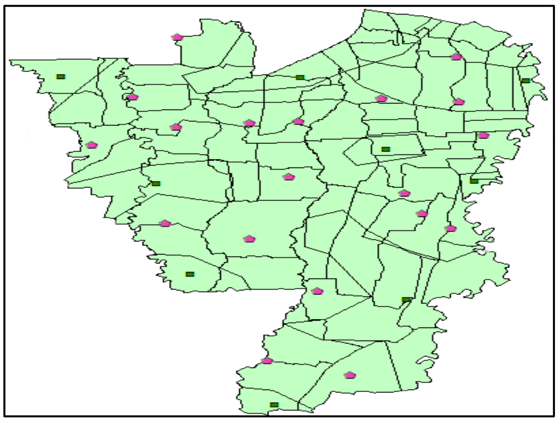

Figure 5. Location of the new fire station

The result of calculation in optimizing the location of fire station that is already done cannot be directly apply to the field. It is because there are some issues regarding with the concern such us: the new location is not optimal, the availability of the land, and accessibility of the area. Therefore, the research needs to be continued with considering those issues. The solution of the issues can be conducted by observe and research using the technology of satellite image.

Relocation of the fire Station

The relocation of the new fire stations is proposed for nine area of polygon which did not get the service from nearest help center. The area of polygon that being observed then initiated as can be seen on the Figure 6.

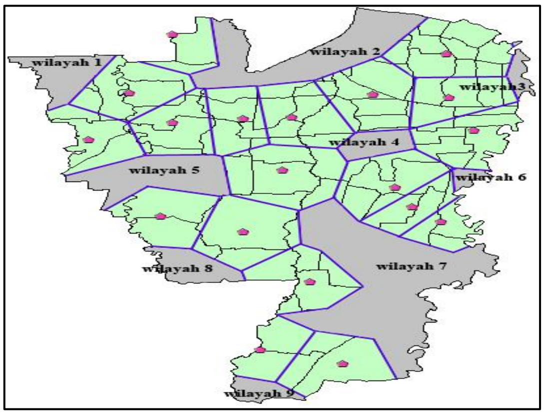

Figure 6. The area of Observation

Discussion

The result of consideration of each area is discussed by mapping the satellite image. The example of discussion of Area 1 can be found as follows:

Area 1

Area 1 consist of Ciledug, Joglo, Pertukangan Utara, and Grogol. In the Figure 7, the green square box are indicated the new location of fire station as the result of optimization.

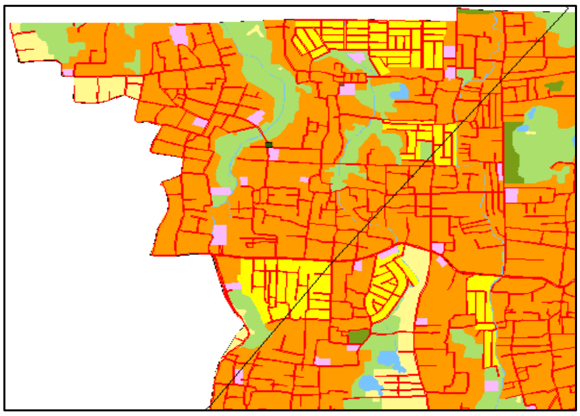

Figure 7. Arcview Satelite Image Area 1

The location then reconsidered based on three main aspects as follow:

Location

The points is located in the strategic crossroad. In the Figure 8, it can be seen that the location of new possible help point is clear so that the new fire station can be build around it.

Optimum Scope

In the Figure 7, it can be seen that Area 1 is mostly consist of densely populated residential. The relocation of the new possible fire station in that area is higly needed.

Accesibility

The new possible fire station is located near by the connecting bridge to Pertukangan Utara area. Therefore, this location has a high accesibility to serve the nearby area. The lenght of main road is quite wide but then the average volume user is also high, so that the new fire station is needed in that Area 1.

Figure 8. The Satelite Image of Area 1

The analysis and research are conducted as the example for the other area. Therefore, in total there are 9 area.

The result of Optimization of Fire Station Location

After all the calculations and considerations of all areas, there area 10 possible new fire station relocation in the South Jakarta area. In Figure 9, nineteen (19) location of fire station before the optimization is indicated with pink pentagon. While the location of the new possible fire station is indicated with blue square in Figure 9.

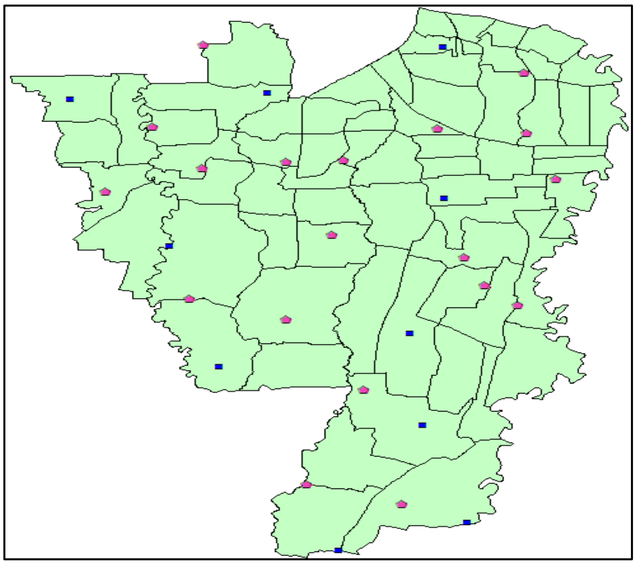

Figure 9. The Location and Relocation of the Fire Station at South Jakarta after the Optimization

CONCLUSION

Using the Mathematics spatial analysis, the current location and possible new location can be identified to be optimize. The placement of fire station at Pasar Minggu Sector is graded as not optimum since the travel distance is too close with the fire station at Pasar Minggu. In order to optimize the function of fire station, it necessary to add 10 more fire stations in the strategic area. After the calculation, observation, consideration, and analysis of all aspects, the 10 fire stations is proposed to be located at Jalan SMA 63 (Ciledug), Jalan Simprug Golf (Simprug), Jalan Karbela Timur (Kuningan), Jalan Mampang Prapatan (Mampang Prapatan) Jalan Deplu Raya (Ciputat), Jalan Harsono RM (Cilandak), Jalan Kelapa Hijau (Jagakarsa), Jalan Universitas Indonesia (Srengseng Sawah), Jalan Karang Tengah (Ciputat),and Jalan Mohammad Kafi 1 (Jagakarsa). This relocation will be able to increase the minimum time travel of fire truck from station to fire area. In instant, it will help to minimize the loss or destruction of the fire if the fire is extinguised quickly. After that, the development of the similar model can be applied to other location with several adjustment in processing the data.

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