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THE ROLES OF NETWORK ANALYSES IN OPTIMIZING THE NUMBER AND LOCATIONS OF FIRE BRIGADE POSTS IN MITIGATING PEATFIRES

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ABSTRACT

Quick responses in managing peatfire disasters in Indonesia are one key success in mitigating and controlling the risk of peatfire disasters. The aim of this study was to simulate and identify the optimum numbers and locations of fire brigade posts for improving their response times in mitigating peatfire events in Bengkalis Island, Riau, Indonesia. Network analyses were applied in the case of peatfire events on this island. The results of this study may assist local governments and fire brigade teams in developing a strategy to manage peatfires systematically. Hence, the results may contribute to the body of knowledge as a reference in systematically controlling peatfire disasters elsewhere in the world. This study proposed five steps in the identification of appropriate locations of fire brigade posts and performs two main steps to achieve this objective: (i) evaluating existing fire brigade posts' service coverages; and (ii) developing three scenarios for simulating additions of one, two, and three posts. The results of this study improve fire brigade dispatch time performances as well as expand their service coverage areas from 40.7% to 62.4% within 60 minutes of dispatch time.

Keywords: Bengkalis; Brigade posts; Dispatched time; Network analyses; Optimizing; Peatfires

1. INTRODUCTION

Indonesia has the largest peatland area of all tropical countries and has the fourth-largest peatland area in the world (Miles et al., 2017). The peatland area in Indonesia reaches 20.6 million ha, encompassing more than 10.8% of the total land in Indonesia (Wahyunto & Subagjo, 2003; Haryono, 2011). In Sumatra, 60% (3.8 million ha) of peatland is located in Riau province. The peatland area on Bengkalis Island (considered the second-largest peatland area in Riau after Indragiri Hilir Regency) was selected as a case study for this article. In fact, in 2015, one of the worse peatfire events in Riau occurred in Bengkalis Regency (1887 events) (World Wide Fund for Nature; WWF, 2016). It was thus interesting to conduct research concerning peatfire mitigation measures to reduce peatfires in Bengkalis (Figure 1). Peatfire events have become an annual disaster affecting social, economic, and Indonesian welfare, especially on the islands of

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Sumatra and Kalimantan (Harrison et al., 2009; Sandhyavitri et al., 2017).

Figure 1 Research location on Bengkalis Island, Indonesia

A number of peatland fire incidents on Bengkalis Island have occurred in the period from 2012 to 2016 (WWF, 2016). The fire incidents spread to two main locations: the middle western and southern areas (Figure 2). Two existing fire brigade posts were located in the District of Bengkalis and Bantan in 2019 (Figure 2b). The objective of this article is to investigate to what extent network analyses may assist in simulating and optimizing the number and locations of fire brigade posts in mitigating peatfires. In the period from 2013–2016, the greatest number of fires (983) occurred in 2014 (WWF, 2016) (Figure 2a). Various efforts have been conducted to mitigate these fire disasters, such as establishing two fire brigade posts. However, it has been acknowledged that the number of these fire brigade posts was too limited to cover the entire island area (WWF, 2016) (Figure 2b).

In fact, no research has been conducted to optimize the appropriate number and locations of fire brigade posts to mitigate peatfire impacts in Indonesia. Hence, there was a need to conduct research to identify the appropriate number of brigade posts and their locations using network analyses.

(a) (b)

Figure 2 (a**)** Hotspot locations from 2013–2016 in Bengkalis, Indonesia; and (b) existing fire brigade posts and road networks in 2017

The island's government and the Local Disaster-prevention Agency (*Badan Penanggulangan Bencana Daerah*; BPBD) must develop a strategic plan for selecting appropriate locations for fire brigade posts in the case of fire disaster events in a large coverage area in time deployment of under 1 hour. This study could be used as a reference in systematically mitigating peatfire disasters, not only in Indonesia but across the world.

The application of various methods for evaluating and identifying appropriate routes, locations, and destinations have been reviewed in several publications, including spatial and travel time relationships, a digital route guided map approach, possible shortest traveling times, and network analyses (Kumar et al., 2014; Sutikno & Murakami, 2015; Beere, 2016; Ranya et al., 2016). This study thus applies network analyses as a method to evaluate and calculate fire brigade dispatch times in Bengkalis, as this application is well-known, generally adopted, and proven to help solve cases of route analysis.

Beere (2016) reviewed applications of road network layer analysis that encompassed spatial and travel time relationships to identify the shortest road access to the nearest health service locations under the uncertainty of traffic congestion. Ranya et al. (2016) explored digital route–guided maps capable of locating health services within a designated area in emergency cases by the application of geographic information systems (GIS) using network analysis based on the shortest possible traveling time under time constraints in Khartoum, Sudan. Kumar et al. (2014) evaluated the safest, fastest ways to transport students from their homes to schools in India. Various variables were considered in the network analyses, including street networks, travel time, speed, and turning movements. The application of GIS software assisted this study to find optimal routes to reach designated schools. Sutikno and Murakami (2015) also used network analyses to evaluate and optimize shelter locations in the case of tsunami evacuation in Japan. A number of service areas for safe tsunami evacuation caused by earthquakes in Indonesia were also discussed in this study, which considered the combination of spatial and network analysis using GIS to improve tsunami mitigation measures. Thawongklang and Tanwanichkul (2016) evaluated an application of production-scheduling techniques for dispatching ready-mixed concrete and indicated that delivery delays could be minimized by improving delivery times, cutting operational costs. This study also used network analyses that encompassed various data inputs, such as distances, travel speed, and travel times, determined by GIS software (ArcGIS). The results have been proven to improve the delivery process performance.

Few studies have reviewed the application of network analyses in improving fire brigade performance, however, especially in abating peatfire disasters. This study utilizes network analyses to optimize the number and locations of fire brigade posts in mitigating peatfire disasters based on GIS. As mentioned, these analyses are common and widely applied in the evaluation and identification of appropriate routes and locations of designated areas. Network analysis, one of the methods provided by GIS software, finds least-impeded paths, such as finding the shortest road networks to transport students to their schools or fire brigade teams to fires (Fischer, 2014; Longley et al., 2001; Miller & Shaw, 2001 Sutikno & Murakami, 2015). Network analysis creates a network dataset and analyzes the network, a method that builds on several ArcGIS virtues, such as ArcCatalog for creating a network dataset, ArcMap for analysis, and ArcMethodbox for geo-processing (Fischer, 2014;; Kumar et al., 2014). The relationship between nodes and arcs in the network analysis is known as network topologies (Fisher, 1995).

2. METHODOLOGY

Peatfire occurrences in the remote areas are often far away from main roads and cannot be reached easily by vehicles. Hence, it is often necessary to reach peatfire destinations by a combination of conventional fire brigade vehicles and on foot. This poses a challenge to simulating a number of transportation network routes using both transportation modes: using vehicles (if a roadway exists) and by foot (if no roadway exists).

The common logical data model supporting the node-arc view is illustrated as networks in a geo-relational model (Longley et al., 2001). This model distinguishes spatial and attribute data into different data models. A logical spatial data model (the "vector data model") that encodes nodes and arcs maintains the geometry and associated topological information, while associated attribute information is managed in relational database management (a relational database management system; RDBMS) tables (Longley et al., 2001; Goodchild, 2001; Miller & Shaw, 2001). In this article, the fire brigade–vehicle routing algorithms can be applied in one of two modes: variable routing and fixed routing. In a variable-routing context, an algorithm is utilized with the actual fire brigade delivery requirements to develop routes for the next planning horizon. Fixed routing is applied when the fire brigade demands are sufficiently stable to allow fire brigade vehicles to repeatedly use the same routes (Fisher, 1995).

2.1. Shortest Path Problem

The shortest path problem (SPP) is a sub-problem in the case of time-constrained routing and scheduling problems (Fischer, 2014). The SPP is the difficulty of searching for the lowest-time route between any two specified nodes in a network that is solved by seeking the shortest route path alternatives (e.g., seeking alternatives for a fire brigade team to the reach a designated location of fire events from a number of road paths). These nodes (locations) are assumed to be visited within specified time intervals (Desrosiers et al., 1995).

This article's research was conducted in two main stages: (i) data collection, including field survey and questioners; and (ii) service area analyses.

2.2. Field Survey and Questions

A field survey was conducted to gather spatial data, measure existing road widths, and identify the two existing fire brigade posts.

Interview questions were developed to identify the fire brigade vehicles' speeds on the main streets in Bengkalis Island. Five respondents (the fire brigade drivers in Bengkalis) were questioned. Based on their answers, the average speed of the fire brigade vehicles was calculated to be 35 km/hour. This result was considered acceptable, as road widths in Bengkalis are relatively narrow (3.5–5.5 meters) for two-way lanes. It was assumed that the average walking speed of fire brigade teams while carrying fire extinguishing equipment (i.e., fire hoses, water pumps, Gensets, and spades) was 3 km/h.

Given these average speeds, the average travel speed of the fire brigade teams to reach peatfire locations by a combination of vehicle and foot using ten simulation hotspot distances was 17.7 km/h (Table 1 and Figure 3).

Table 1 Average speed

Fire spots	Travel speed (Km/h)
1	14.61
2	13.88
3	14.46
4	15.43
5	13.41
6	17.32
7	19.23
8	22.45
9	25.72
10	20.81
Total	177.31
Average speed (Km/h)	17.73

Five criteria were used to identify the appropriate locations of fire brigade post: (i) proximity to densely populated areas; (ii) proximity to business areas (e.g., central business districts); (iii) proximity to local government office districts (e.g., the sub-district offices Kantor Lurah or Kepala Desa), health service facilities (e.g., Puskesmas), and traditional cultural centers (e.g., Kantor balai adat); (iv) accessibility of main roads; and (v) accessibility of main infrastructure services and facilities, such as telecommunication, electricity, and water supply.

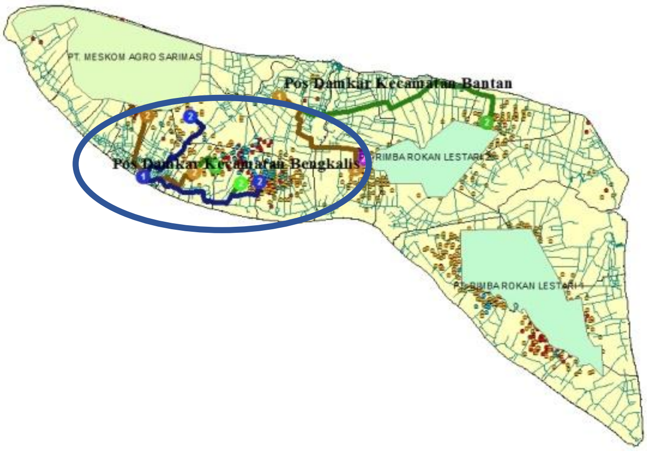


Figure 3 The simulation of hotspot distances in Bengkalis Island using networks analyses

2.2. Service Area Analyses

In this study, the distributions of service coverage areas were divided into five categories based on dispatch time: excellent (green, 0–30 minutes of the dispatch time), good (blue, 31–45 minutes), enough (yellow, 46–60 minutes), poor (orange, 61–75 minutes), and very poor (red, 76–90 minutes) (the Public Works regulation No. 20/2009).

2.3. The Coordinate System

The coordinate system used in this article was World Geodetic System 1984, the Universal Transverse Mercator (WGS 1984 UTM) Zone 48N to map the Earth's elliptical surface onto a two-dimensional map. Two steps were taken to set coordinates: (i) evaluating existing fire brigade posts' service coverage performances; and (ii) developing three scenarios for calculating the proposed number and locations of fire brigade posts to identify the optimize their service coverage areas and response times.

3. RESULTS

In this section, the "prospected" number and locations of the fire brigade posts refer to future plans suitable for Bengkaslis Island.

3.1. Evaluation of the Existing Conditions of Two Fire Brigade Posts' Service Coverages

Two fire brigade posts, one located in Bengkalis District and the other Bantan District, were evaluated. The Bengkalis district post, established in 2013, was the first and is the largest on Bengkalis Island (Figure 4a). This post was located at 1° 28'07" latitude and 102° 06'34" east longitude (Figure 4b) and was fully equipped with fire tankers and fire trucks to extinguish fires.

The other fire brigade post was located at 1° 32"01" latitude and 102° 13"07" east longitude in Selat Baru Village, Bantan district. Every day, six personnel stood by at this post (Figure 5b).

Based on these two existing fire brigade posts, it was calculated that the maximum area they could cover in under 60 minutes of dispatch time in the case of a peatfire was 20.33% + 12.53% + 7.86% = 40.72% (Figure 5a).

(a) (b)

Figure 4 (a) The Bengkalis district fire post and (b) the locations of the two fire brigade posts: Bengkalis district in the south, Bantan district in the north.

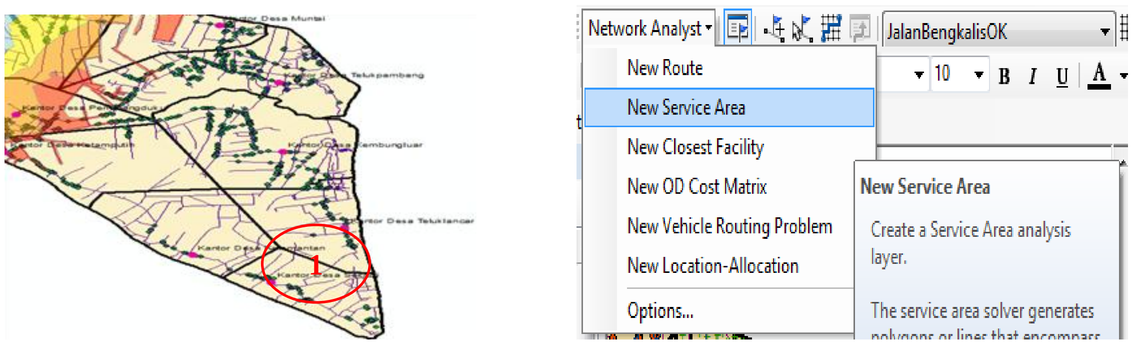
(a) (b)

Figure 5 (a) Map of the existing fire brigade post service area; and (b) the percentages of their service coverage areas

The areas covered by the existing posts were limited to the southern and northern parts of Bengkalis Island, leaving the eastern part unserved and a need to establish additional fire brigade posts. To optimize the number and location of fire brigade posts, this article develops 3 main scenarios.

Scenario 1. Establishing One Additional Fire Brigade Post (Total of Three Posts)

Figure 6 shows some appropriate locations of proposed additional fire brigade posts close to the local sub-district offices (Desa Kalimantan) at the lower end of the island.



(a) (b)

Figure 6 (a) Local district offices located within the western part of Bengkalis Island (uncovered fire brigade post services); and (b) network analyses menu in ArcGIS for calculating additional fire brigade posts

It was expected that the establishment of a third post (in the circle labeled “1”) would cover six local sub-districts: Desa Ketam Putih, Muntai, Teluk Pambang, Kembung Luar, Teluk Lancar, Kelemantan, and Sekodi. Figure 6 shows the network analysis menu in ArcGIS, which was utilized to add some fire brigade posts. Based on the third post simulation, it was identified that green, blue, and yellow areas became covered the fire brigade performances improved (Figure 7b).

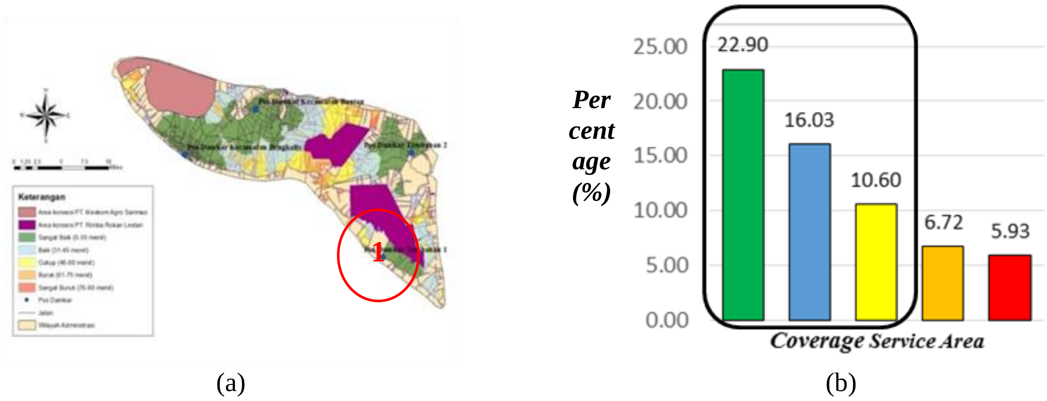


Figure 7 (a) Map of fire brigade post service area and the location of the proposed new post (in the circle labeled “1”); and (b) percentages of the coverage service areas in scenario 2

Based on the ArcGIS result, the maximum coverage area that could be served by the fire brigade teams increased by 21.50% from 40.72% (the existing coverage) to 22.90% + 16.03 + 10.60 = 49.50% (scenario 1) (Figure 7). This was due to a significant distance reduction in the southern island area. The shorter the designated distance, the more time could be saved (Thawongklang & Tanwanichkul, 2016).

Scenario 2. Establishing Two Additional Fire Brigade Posts (Total of Four Posts)
The existing fire brigade posts cannot reach Muntai Village, Teluk Pambang Village, Kembung Putih Village, or Kembung Luar Village in under 60 minutes (Figure 8a, and 8b).

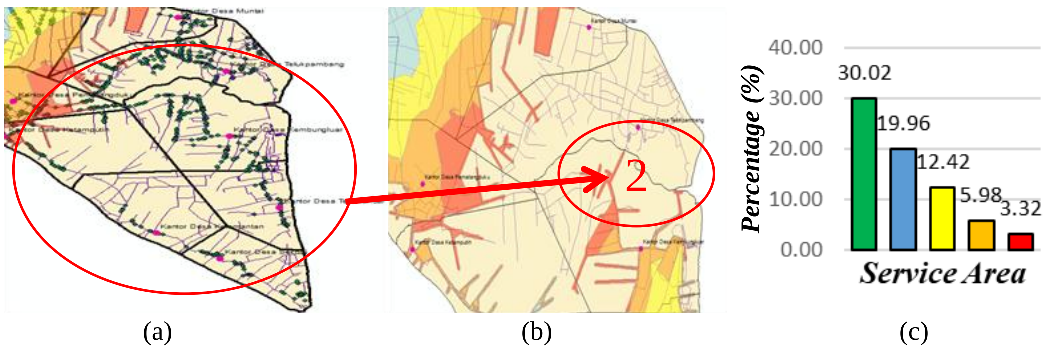


Figure 8 (a) Unreachable areas with the existing posts; (b) the location of the proposed new post (in the second circle labeled “2”); and (c) percentages of the coverage service areas in scenario 2

To reach them, one more post needs to be established in Teluk Pambang Village. A network analysis was performed; Figure 8c illustrates its results.

Based on the simulation of two additional fire brigade posts (a total of four posts) in Figure 9, the service coverage area increased 53.24% from 40.72% (the existing coverage) to 30.02% + 19.96% + 12.42% = 62.40% (with dispatch time under 60 minutes), reducing fire impacts on the community (the Public Works regulation No. 20/2009).

Scenario 3. Establishing Three Additional Fire Brigade Posts (Total of Five Posts)

This scenario added one more post in Pematang Duku Village to correct the absence of the fire service coverage there. An analysis of the service area was again performed by including the existing posts and the scenario 2 posts. Figure 9 presents the results.

(a) (b)

Figure 9 (a) Map of the fire brigade post service area and the location of the proposed new post (in the circle labeled "3"); and (b) percentages of the coverage service areas in scenario 3 (with an additional three posts)

With this additional post, the green coverage area increased by 55.75% from 40.72% (the existing coverage) to 35.20% + 18.00% + 10.22% = 63.42% (scenario 3).

4. DISCUSSION

Based on the network area analyses obtained from ArcGIS, ArcCatalog, ArcMap, and ArcMethodbox, the geo-processing results show that the existing two fire brigade posts have total combined service coverage in Bengkalis Island of 40.7% of the island area.

Table 2 Results summary

Scenario No.	Scenario	Coverage Area (Travel Time ≤60 Minutes)	Incremental Service Coverage Area
1	Two fire brigade posts	40.72%	0%
2	Three fire brigade posts	49.50%	21.50%
3	Four fire brigade posts	62.40%	53.24%
4	Five fire brigade posts	63.42%	55.75%

After conducting the network analyses, the service coverage of the fire brigade posts improved significantly from 40.7% (scenario 1) to 63.4% (scenario 4) (Table 2) as the result of additional fire brigade posts. Hence, network analyses may assist the development of various simulations for improving service coverage areas and improving the dispatch times of fire brigades to systematically mitigate and control peatfire disasters (Harrison et al., 2009; Sandhyavitri et al., 2017).

Of the four options, scenario 4 (a total of five fire brigade posts) was the best result based on its improvement of service coverage area.

5. CONCLUSION

Network analysis may assist governments in developing strategies for improving service coverage areas of fire-prevention teams for constrained dispatch times. Based on the network area analyses obtained from the ArcGIS, ArcCatalog, ArcMap, and the ArcMethodbox, the geo-processing results show that the two existing fire brigade posts have service coverage in Bengkalis Island of only 40.7%. This study simulated the additions of one, two, and three fire brigade posts, which improved fire brigade service coverage by 55% (from 40.7% to 63.4%).

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