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Implementation of K-Means Clustering in Recognizing Crime Hotspots and Traffic Issues Through GIS

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ABSTRACT

The challenge of accurately identifying instances of crime and traffic issues has rendered the precise localization thereof difficult, thereby impeding the populace's access to information concerning areas of high risk and safety. Employing a Geographic Information System (GIS)-based mapping system utilizing the K-means clustering method, spatial data pertaining to crime and traffic concerns are grouped. The primary objective is to aid in the identification of high-risk areas concerning crime and traffic matters. The methodology employed in this study revolves around the application of the K-means clustering method to categorize spatial data relevant to crime and traffic issues. K-means clustering represents a non-hierarchical cluster analysis technique designed to partition data into multiple groups based on spatial similarities. Research findings elucidate that through the utilization of the K-means clustering method, three distinct sets of clusters predicated upon the intensity of crime and traffic issues emerge. Consequently, from these clustering outcomes, districts and specific locales falling within each cluster, denoted as moderately vulnerable (C1), vulnerable (C2), and highly vulnerable (C3), can be delineated. This system is poised to furnish recommendations to pertinent authorities for addressing areas exhibiting heightened intensity levels while concurrently facilitating the generation of reports and dissemination of information to the public via a dedicated website pertaining to areas at elevated risk of crime and traffic issues.

Keywords: Clustering, Criminality, GIS, K-means, Traffic Issues

INTRODUCTION

Information technology has now become commonplace among society, requiring fast and easy information processing (Khairiyati et al., 2020). One of the latest innovations is the integration of information systems with geography, known as Geographic Information Systems (GIS) (Riswandi et al., 2023). GIS encompasses hardware, software, geographic data, and human resources that effectively work to input, store, update, manage, manipulate, integrate, analyze, and display geographically based data (Husada et al., 2020).

The Batu Bara District Police, under the North Sumatra Regional Police, are responsible for addressing various security and criminal issues in the community. The results of interviews indicate that criminal cases include theft, assault, fraud, child abuse, embezzlement, domestic violence, gambling, vandalism, defamation, and threats. Traffic problems faced include accidents and congestion.

The Batu Bara District Police are responsible for managing criminal case data and traffic issues to enhance public awareness. However, the lack of monitoring and recording of vulnerable areas results in insufficient information about the locations where crimes and traffic problems occur frequently. Traditional methods such as using monthly whiteboards are ineffective, reducing the level of vigilance in securing those areas. Therefore, a supporting application capable of analyzing and providing more comprehensive information is needed to anticipate quickly in areas prone to crime and traffic issues. With the Geographic Information System (GIS) in place, it is hoped that the Batu Bara District Police can improve service and facilitate the dissemination of information, especially regarding security, traffic, and the management and operational aspects of regional security.

Based on the above issues, a computerized mapping information system will be developed for areas prone to crime and traffic problems in the Batu Bara District. This system will manage geographic data and provide information about crime and traffic problem hotspots, categorized by severity levels as moderately risky, risky, and highly risky. The categorization will be done using the k-means clustering algorithm, which separates data with similar characteristics into different groups (Moruk et al., 2024).

In the study conducted by (Dwirohayati, 2020) on mapping crime-prone areas using the k-means clustering method at the Bandar Lampung City Police Department, a web-based mapping system was developed. This research resulted in the creation of a mapping system using the k-means clustering method, which facilitated the recording of

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criminal activities by the City Police Department. (Widodo, 2018) also conducted research at the Temanggung District Court, which led to the development of a geographic information system for mapping criminal cases. The key difference from the previous system lies in its expanded coverage of various types of criminal activities and traffic issues, as well as the inclusion of public complaint services and validation by the Batu Bara Police Resort to prevent the inclusion of invalid data. This system also provides information on case details and resolution times

LITERATURE REVIEW

Based on previous research conducted by M. Thariq Nugroho in 2019, a case study on flood-prone areas using the K-Means method in Jember Regency resulted in a system that implements K-Means Clustering for the classification of flood-prone areas. The clustering results are divided into five groups: High Flood, Moderate Flood, Low Flood, Flood Safe, and Non-Flood, with five variable criteria for calculation, namely Soil Type, Land Slope, Land Use, River Buffer, and Rainfall (Thariq, 2019).

Furthermore, in 2020, a study by Defi Dwirohayati titled "Mapping Crime-Prone Areas Using K-Means Clustering at Bandar Lampung Police Resort" produced a mapping system using the K-Means Clustering method based on a website. This system can be utilized by POLRESTA and POLSEK to record criminal activities on a daily, weekly, monthly, and yearly basis. Additionally, the system provides recommendations to authorities to enhance surveillance in areas prone to crime, with the aim of making Bandar Lampung City safer and more secure (Dwirohayati, 2020).

Subsequently, a journal article discussing the application of the K-Means Clustering Method for Mapping Traffic Accident-Prone Areas in Malang City based on a website by Arninda Agnes Vernanda et al. in 2021 resulted in a website-based mapping system with three clusters: very prone, prone, and moderately prone. This system maps areas prone to traffic accidents in Malang City (Vernanda et al., 2021).

Based on previous research, this study aims to innovate by applying K-Means Clustering to determine two vulnerable areas: crime-prone areas and traffic problem-prone areas based on Geographic Information Systems (GIS) in Batu Bara Regency. The developed system will assist the public in reporting incidents they encounter through the website, enabling authorities to follow up through the system and provide information to the people of Batu Bara Regency about the location and condition of areas prone to crime and traffic problems.

METHOD

In this study, the researcher applied the Research and Development (R&D) research method and adopted data collection techniques including observation, interviews, literature review, and documentation. The aim of this research was to implement the K-means clustering method in categorizing spatial data related to crime and traffic issues in the research area. Additionally, system development was conducted using the waterfall method approach, known for its systematic and sequential approach to system construction.

Research Methodology

The type of research employed in this study was Research and Development (R&D). According to Borg and Gall (as cited in Sugiyono, 2019), Research and Development is a method used to validate or develop a product. Validation refers to renewing existing products or creating new ones. To produce a specific product, research is needed to analyze its needs and test its effectiveness so that it can function effectively in society.

The steps undertaken in this research method began with an analysis of the needs or problems faced, followed by the creation of a research plan, formulation of the problem, setting of problem boundaries, determination of research objectives, and literature review to gather information using specific techniques. Subsequently, product development aligned with the research objectives was conducted. After the product was produced, testing was conducted gradually, starting with initial field tests, which involved testing and operating the main product version, with improvements made if necessary. Furthermore, primary testing of the product was carried out in a single stage, known as the main field test, along with a functional product review to facilitate broader product development and test product suitability until the product was deemed ready for use.

Data Collection Techniques

The data collection techniques employed included observation, interviews, and literature review. Observations were systematically conducted on research objects, such as crime data and traffic issues. Interviews were conducted with the Head of Human Resources Development Division to gather information regarding the handling of crime data and traffic issues, as well as the challenges faced in disseminating information to the public. Literature review involved

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learning from various sources, such as books and journal articles, discussing geographic information systems with the K-means clustering method.

K-Means Clustering

K-Means clustering was a popular algorithm that divided data into clusters based on the distance from the centroid of each cluster. Users were required to specify the desired number of clusters ('k'). Each data point would then be assigned to the cluster with the closest centroid to that point (Maharrani et al., 2024). K-Means was a non-hierarchical clustering method that categorized data into one or more clusters, grouping together data with similar characteristics while separating those with different characteristics (Istianto & 'Uyun, 2021).

The fundamental process of the K-Means algorithm (Putra & Hartomo, 2021) is outlined as follows:
Determine k as the desired number of clusters to be formed, and arbitrarily assign cluster centers.
Calculate the distance from each data point to the cluster centers using the Euclidean equation

$$d_{ik}\sqrt{\sum_j^m (Cij - Ckj)^2} \quad (1)$$

Group the data into clusters with the shortest distances using the equation.

$$\text{Min}\sum_{k=1}^{k} d_{ik} = \sqrt{\sum_i^m (Cij - Ckj)^2} \quad (2)$$

Calculate the new cluster centers using the equation.

$$C_{kj} = \frac{\sum_{i=1}^{p} x_{ij}}{p} \quad (3)$$

Repeat Steps 2 through 4 until no more data points move to other clusters.

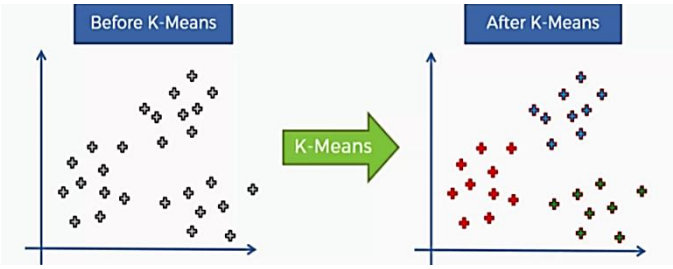

Fig. 1 K-Means Clustering (Wanto et al., 2020)

In the initial stage, identify items within a specific distance and then merge those items into a single cluster. Calculate the distance between clusters, and repeat the process from the beginning until all items are connected.

System Development Methodology

In this system, the system development methodology utilized the waterfall approach, which was a systematic method or a follow-up method of system formation.

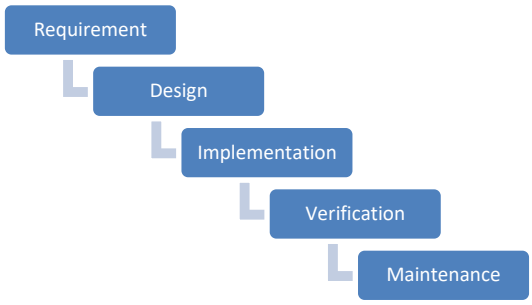

Fig. 2 The Waterfall Methodology

The waterfall method was a commonly used approach in system development, where processes were carried out sequentially and linearly. Its stages included (Setiawan & Triase, 2023).

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Requirement Analysis
Involving data collection through observation, interviews, and literature review to identify issues and understand system requirements.

Design
Creating system designs based on user requirements using UML and designing simple and understandable web interfaces.

Implementation
Building the system by coding using PHP and JavaScript, and utilizing MySQL as the data storage medium.

Verification
Conducting trials to ensure the system functions properly according to the given inputs.

Maintenance
The final stage involving system installation and responsibility to ensure smooth system operation and enhance its capabilities if necessary.

RESULT

Requirement Analysis

Analysis of Current System Operation

The current system analysis was conducted by delineating the system flow within the research object. The processes of recording, report generation, and mapping of vulnerable areas still relied on conventional methods.

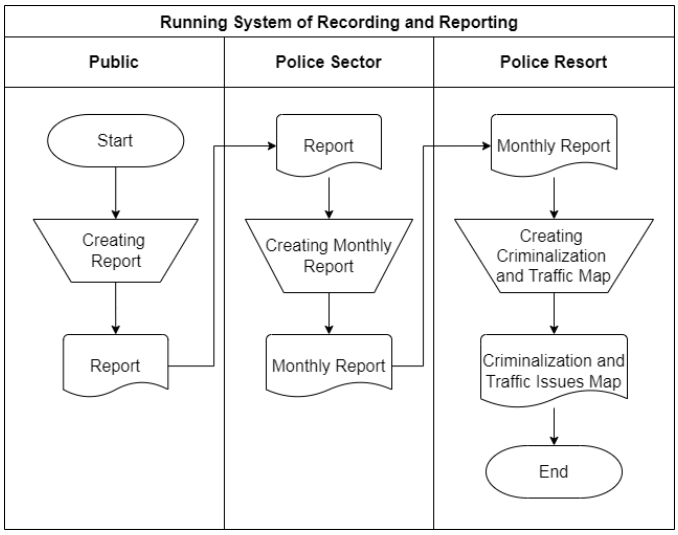

Fig. 3 System Operation Diagram

In the diagram above (Figure 3), the operational system depicted the manual usage of the crime recording and traffic problem system, potentially leading to data processing errors and consuming significant time. Additionally, constraints arose in disseminating this information to the public.

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System Proposal Analysis

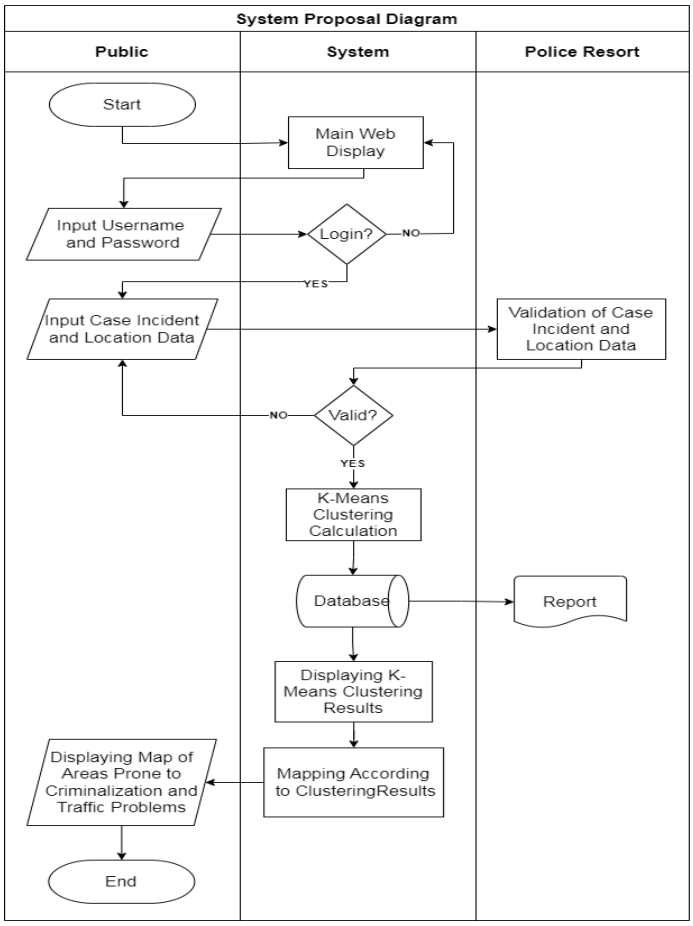

Fig. 4 Proposed System Diagram

Figure 4 depicted the proposed system flowchart for recording, data collection, and mapping of High Crime and Traffic Problem Areas within the research object. With web-based technology, the information process became fast and easy. Mapping of vulnerable areas through the website would assist the Police Resort in monitoring and safeguarding areas highly susceptible to crime and traffic issues.

K-Means Cluster Analysis

The clustering using K-Means aimed to group data with similar characteristics into one cluster and data with different characteristics into another cluster. The data used in the calculation experiments were crime and traffic problem data from 2017 to 2022 in the research object.

Clustering Crime and Traffic Data

The initial step in the k-means method was to determine the number of clusters to be formed, followed by the determination of initial centroids. The initial centroid values were randomly selected from the data objects. Subsequently, the distance between each data point and the centroid was calculated using the Euclidean distance formula.

The results of crime clustering using the k-means clustering method can be seen in Table 1.

Table 1. The Results of Crime Clustering

No	District Areas	*Cluster*	Description
1	Air Putih	C2	Vulnerable
2	Datuk Lima Puluh	C1	Moderately Vulnerable
3	Datuk Tanah Datar	C1	Moderately Vulnerable

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No	District Areas	*Cluster*	Description
4	Laut Tador	C3	Highly Vulnerable
5	Lima Puluh	C1	Moderately Vulnerable
6	Lima Puluh Pesisir	C3	Highly Vulnerable
7	Medang Deras	C3	Highly Vulnerable
8	Nibung Hangus	C2	Vulnerable
9	Sei Balai	C1	Moderately Vulnerable
10	Sei Suka	C3	Highly Vulnerable
11	Talawi	C2	Vulnerable
12	Tanjung Tiram	C2	Vulnerable

The results of traffic problem clustering using the k-means clustering method can be seen in Table 2.

Table 2. The Traffic Problem Clustering Results

No	District Areas	*Cluster*	Description
1	Simpang 4 Lima Puluh Kota	C3	Highly Vulnerable
2	Perlintasan Rel KA Lima Puluh Kota	C1	Moderately Vulnerable
3	Simpang 3 Taman Lima Puluh Kota	C1	Moderately Vulnerable
4	Pintu Keluar TOL Lima Puluh	C1	Moderately Vulnerable
5	Perbatasan Batu Bara – Simalungun	C2	Vulnerable
6	Simpang 4 Simpang Dolok	C2	Vulnerable
7	Simpang 3 Padang Genting	C2	Vulnerable
8	Tugu Simpang 4 Tanjung Tiram	C2	Vulnerable
9	Jalan Pasar Tanjung Tiram	C2	Vulnerable
10	Simpang Pantai Bunga	C1	Moderately Vulnerable
11	Simpang Jalan Perintis Manunggal	C1	Moderately Vulnerable
12	Simpang Limau Manis	C2	Vulnerable
13	Jalan SPBU Petatal	C2	Vulnerable
14	Simpang Sei Bejangkar	C3	Highly Vulnerable
15	Perlintasan KA Petatal	C1	Moderately Vulnerable
16	Jalan Istana Niat Lima Laras	C1	Moderately Vulnerable
17	Simpang 4 Jalan Ujung Kubu	C1	Moderately Vulnerable
18	Jalan Pajak Selasa Simpang Gambus	C3	Highly Vulnerable
19	Jalan Lintas Sumut Tanah Gambus	C2	Vulnerable
20	Jalan Lintas Sukaraja	C2	Vulnerable
21	Simpang 4 Tanah Merah	C3	Highly Vulnerable
22	Jalan Lintas Indrapura	C3	Highly Vulnerable
23	Jalan SPBU Indrapura	C2	Vulnerable
24	Pintu Tol Indrapura	C1	Moderately Vulnerable
25	Simpang 3 Tugu Inalum	C3	Highly Vulnerable
26	Simpang 3 Bandar Tinggi	C3	Highly Vulnerable
27	Simpang Tanjung Kasau	C1	Moderately Vulnerable
28	Jalan Access Road Inalum	C2	Vulnerable

Design

The design phase of the Geographic Information System for mapping areas vulnerable to crime and traffic problems using the k-means clustering method required supporting tools in the form of use case diagram and class diagram designs.

Use case diagram

The use case diagram depicts the interaction between actors and the system (Batubara & Nasution, 2023). Here, the use case diagram was employed for the case study of mapping the Geographic Information System for areas vulnerable to crime and traffic problems using the k-means clustering method.

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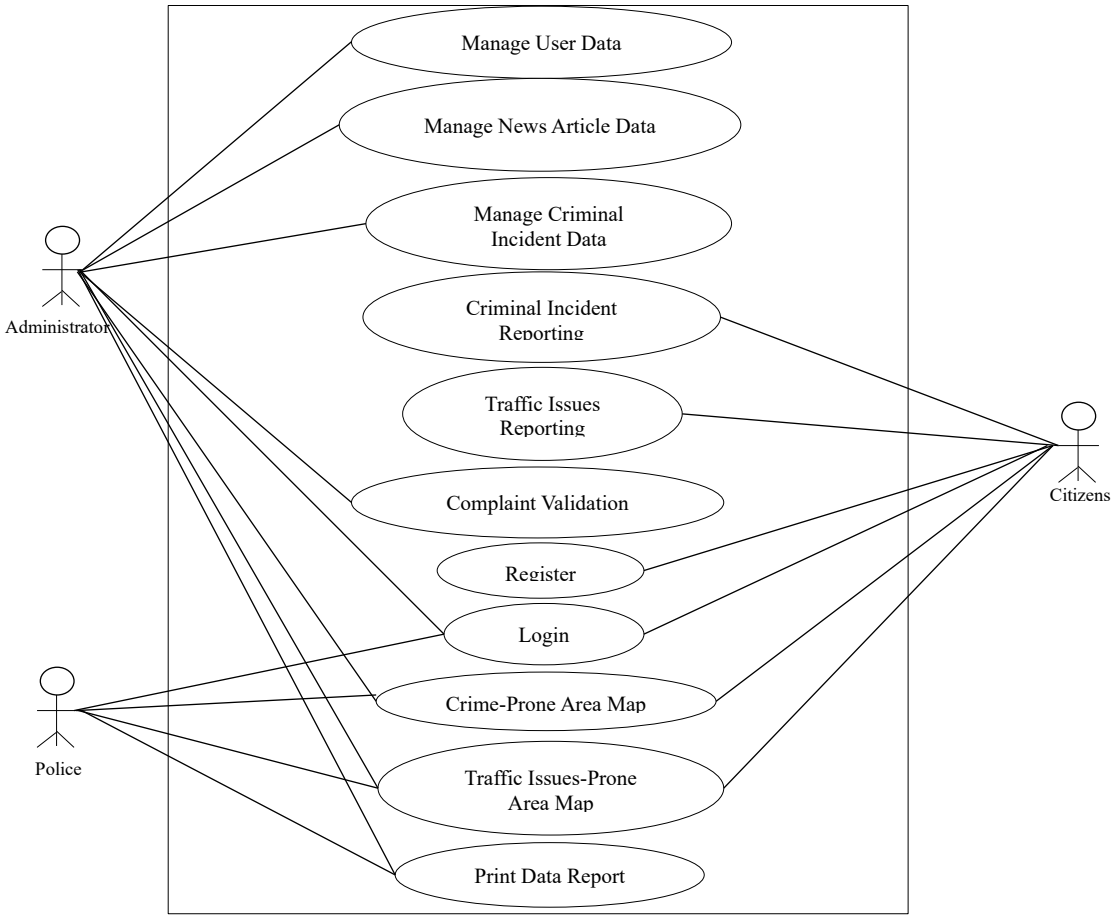

Fig. 5 Use Case Diagram

The use case diagram was a functional representation of the system, depicting the expected tasks. It encompassed functions such as inputting crime and traffic problem incidents data, managing user and incident data, as well as incident validation. This diagram aided in elucidating the features utilized by users in the system under development.

Implementation

In the implementation phase, the previously designed user interface was translated into programming languages.

Home Page

The Home Page served as the initial page seen when opening the website. It contained brief information about the system, news articles, and a map.

Fig. 6 Home Page Design

Crime Vulnerability Level Page

The Crime Vulnerability Level Page displayed a map and a table of crime vulnerability level data visible to the public, administrators, and leaders.

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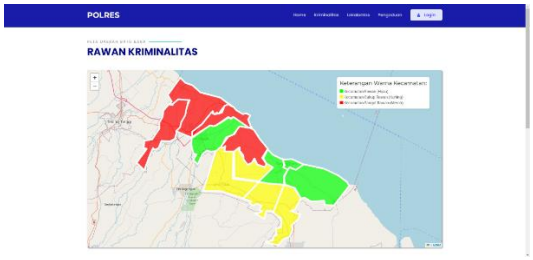

Fig. 7 Crime Vulnerability Level Map Design

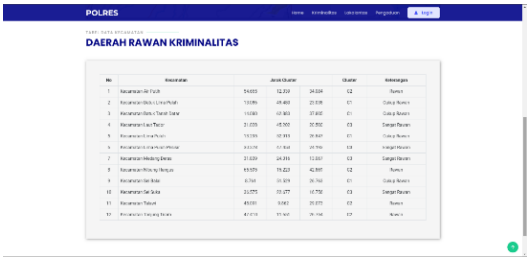

Fig. 8 Crime Vulnerability Level Table Design

Traffic Problem Vulnerability Level Page

The Traffic Problem Vulnerability Level Page displayed a map and a table of traffic problem vulnerability level data visible to the public, administrators, and leaders.

Fig. 9 Traffic Problem Vulnerability Level Map Design

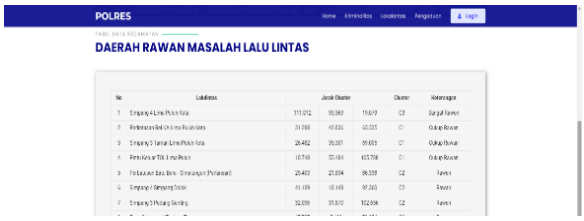

Fig. 10 Traffic Problem Vulnerability Level Table Design

Complaint Page

The Complaint Page allowed users to report newly occurred crime and traffic problem incidents. Within the complaint page, users would input several required pieces of information.

Fig. 11 Crime Complaint Form Design

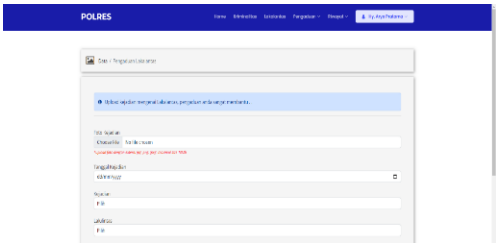

Fig. 12 Traffic Problem Complaint Form Design

Complaint History Page

The Complaint History Page provided information on the status of complaints that had been filed, including whether they were processed as valid or invalid by the administrator.

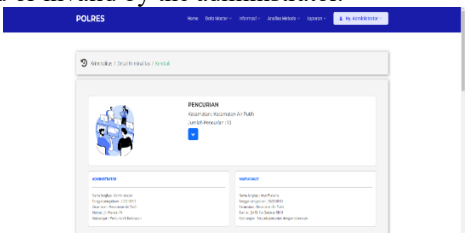

Fig. 13 Complaint History Design

Complaint Verification Page

The Complaint Verification Page was managed by administrators to verify complaints submitted by users.

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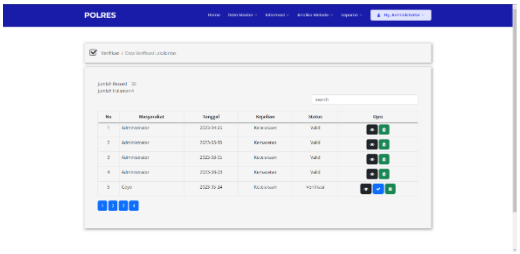

Fig. 14 Complaint Verification Page Design

District Data Page

The District Data Page displayed districts and could be managed by adding, editing, and deleting them.

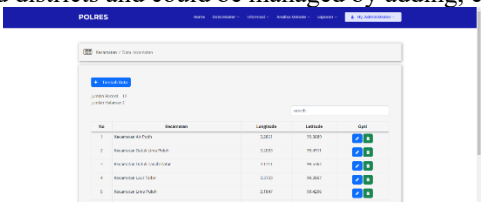

Fig. 15 District Data Page Design

Traffic Location Point Data Page

The Traffic Location Point Data Page provided information on traffic location points managed by administrators.

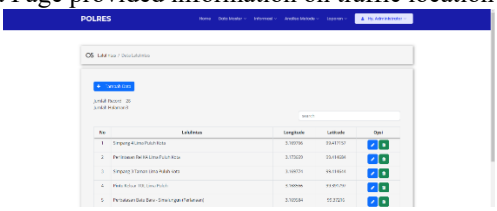

Fig. 16 Traffic Location Point Data Page Design

Crime Data Page

The Crime Data Page contained a table of crime incident data managed by administrator accounts.

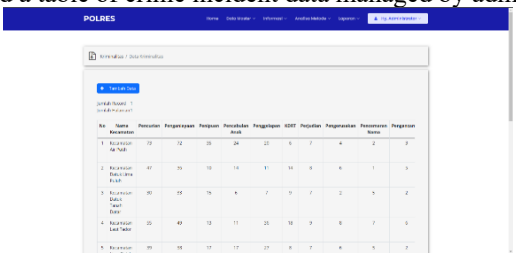

Fig. 17 Crime Data Table Design

Crime Incident Detail Page

The Crime Incident Detail Page allowed viewing detailed data on crime incidents.

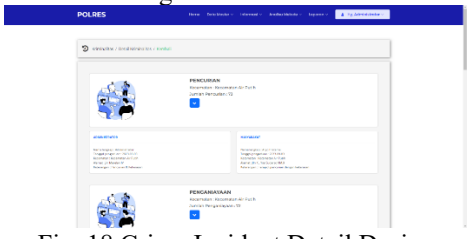

Fig. 18 Crime Incident Detail Design

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Traffic Problem Data Page

The Traffic Problem Data Page displayed a table of all traffic problem data managed by administrators.

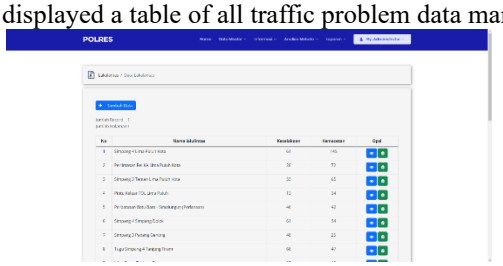

Fig. 19 Traffic Problem Data Table Design

K-means Clustering Method Analysis Page

The K-means Clustering Method Analysis Page displayed the results of analysis and calculations on incoming data.

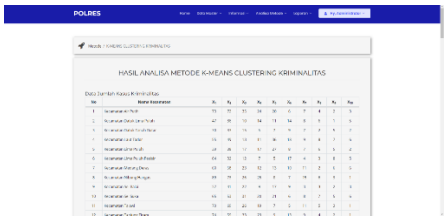

Fig. 20 Clustering Analysis Result Page Design

Verification

System testing aimed to evaluate the system's success based on the research planning objectives (Wulaningrum et al., 2022). Black box testing was primarily conducted on the system's display and menu functions without inspecting the source code (Syaidaturrahmi & Ikhwan, 2022). Below is the table of the system testing design.

Table 3
The Testing Table

No	Testing Description	Testing Procedure	Expected Results	Results
1	Complaint Form	Click on the Crime Complaint or Traffic Accident Complaint menu and fill in all the required data, then click submit	The system displays the complaint form page and directs to the Complaint History page after submission	✓
2	Viewing Vulnerability Levels	Click on the Crime or Traffic Accident menu, then click on one of the districts or points on the map	The system will display the vulnerability level mapping along with a pop-up displaying the district's name	✓
3	Adding Traffic Accident Location Data	Fill in the add data form, then click save	The system executes a query to add data to the database according to the input and updates the view listing of the latest account data	✓
4	Adding Criteria Data	Fill in the add data form, then click save	The system executes a query to add data to the database and updates the view listing of the latest account data	✓
5	Verifying Complaints	Click on the Master Data Verification menu	The system displays a list of complaint data, with options to view complaint details, verify, and delete	✓
6	Viewing and Adding News Article Data	Click on the News Article Information menu, then fill in the add data form and click save	The system displays a list of news articles with options to add data, edit, and delete. After the user selects an action, the article list displays with the latest data	✓
7	Viewing Clustering Analysis Results	Click on the Method Analysis menu	The system displays the results of the analysis and calculation of the k-means clustering method	✓

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DISCUSSIONS

This research has developed a system that requires testing to ensure its functionality. Program or system testing aims to identify errors in the program, either manually or automatically. Testing ensures that all requirements are properly fulfilled. The main goal of testing is to ensure that the system runs well and is suitable for mass production. The system has been tested using black box testing, where every page and menu in the system is tested and performs as expected. Based on the research results and discussion on mapping crime-prone areas and traffic issues using the k-means clustering method based on a website, the next step in research development is to expand this system by including a broader range of criminal activities and integrating direct incident location points into the traffic problem system using coordinates.

CONCLUSION

This research resulted in a web-based mapping system using the k-means Clustering method. The clustering results showed three sets of clusters, where four districts in cluster (C1) were moderately vulnerable, four districts in cluster (C2) were vulnerable, and four districts in cluster (C3) were highly vulnerable to crime. An analysis of traffic problems also found that ten location points in cluster (C1) were moderately vulnerable, eleven location points in cluster (C2) were vulnerable, and seven location points in cluster (C3) were highly vulnerable. This system, which integrated spatial data based on clustering, was capable of providing recommendations to authorities regarding necessary measures in areas with high levels of crime and traffic issues. In addition to aiding in the preparation of reports for authorities, the website also disseminated information to the community at the research site about vulnerable locations and areas. This system had the potential to enhance security and tranquility, as well as facilitate the public in reporting incidents without having to directly visit the police station, simply by utilizing the provided website.

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