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The MxT Model: Leveraging Social Media Data for Real-Time Route Optimization in Disaster-Prone Urban Transport Networks

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ABSTRACT

The modified xTRoad (MxT) model, an innovative route optimization framework, is presented to enhance urban traffic management within disaster-prone regions. This model uniquely integrates static and real-time data derived from the social media platform X (formerly known as Twitter) to improve route mitigation strategies, particularly during emergencies. The methodology employs a refined social media data extraction process using Boolean logic and a score-based evaluation system to identify disruptions, including flooding, obstructive debris, and public demonstrations. To validate the accuracy of the model, ground truth validation techniques were implemented, confirming the system's efficacy in detecting obstacles and generating alternative routes. Performance testing was conducted on key transport arteries in Jakarta, where the MxT model demonstrated a detection accuracy exceeding 91.6% for traffic disruptions. Furthermore, the model achieved an average reduction in travel time by 15% compared to traditional traffic management systems. The MxT model dynamically adapts to real-time conditions, offering safer and more efficient navigation options in complex urban settings. The results underscore the MxT model's potential as a scalable, adaptable solution for intelligent transport management during disaster scenarios, thereby contributing to the advancement of resilient urban infrastructure.

1. INTRODUCTION

As one of the most congested cities in the world, Jakarta faces significant challenges in traffic management mainly when disruptions, such as flooding, fallen trees, and demonstrations, occur. According to the World of Statistics report [1], Jakarta is the 10^{th} most congested city in the world and the only one in Southeast Asia to make the top 10 list. This congestion increases the risk of accidents and delays that harm the economy and public welfare. Flooding in Jakarta is reported to cause losses of more than IDR 1 trillion, disrupting trade and industry sectors.

Traditional traffic detection technologies, which usually focus only on congestion, often fail to anticipate obstacles such as flooding and accidents, especially in disaster-prone megacities such as Jakarta. In other countries, data from social media has proven useful. For example, UK research uses data from the X platform to detect congestion and accidents [2]. Social media is also used in Brazil as additional data in intelligent transportation systems [3]. In other studies, deep learning techniques have been utilized to enhance traffic predictions by leveraging data from social media platforms [4]. Deep learning algorithms such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) have been widely used to predict traffic congestion with better accuracy [5].

The X platform as a data source is increasingly relevant in Indonesia, the country with the 4^{th} most significant number of users worldwide as of July 2023 [6]. Research on data from the X platform to extract information about traffic conditions in Indonesia showed an accuracy of more than 90% in classification and an F1-score of 70% for the Named Entity Recognition (NER) technique [7]. Atikah et al. [8] used deep learning-based multi-label classification to detect traffic events from tweets in Surabaya. Afrizal and Timur [9] categorized traffic congestion and density in Yogyakarta using data from the X platform and the Global Positioning System (GPS). Abdullahi et al. [10] highlighted how integrating ICT into transportation systems enhances efficiency, accessibility, and sustainability while addressing the unique challenges of urban mobility. Similarly, Pistsov and Zakharov [11] emphasized that optimizing public transportation priority methods requires adaptive approaches tailored to specific traffic conditions and passenger demands. These insights underline the necessity of designing traffic management systems that are both adaptive and efficient, particularly in dynamic environments like Jakarta, which frequently faces disruptions from natural disasters. This challenge highlights the need to optimize traffic management systems to offer more adaptive and efficient alternative routes. This research aims to provide a more responsive solution to Jakarta's traffic issues, particularly in disaster-prone areas.

This study is needed because Jakarta faces various challenges in traffic management during disasters, which often worsen congestion and slow emergency response. Flooding, a routine problem, often leads to the closing of several main roads, disrupting community mobility and causing public and goods transportation delays. In addition, fallen trees and landslides often occur due to heavy rains and strong winds, adding to the list of road obstacles. Demonstrations and fires in densely populated areas also contribute to traffic blockages. The situation is further complicated by the lack of adaptive traffic management systems and real-time data that can provide alternative routes quickly and accurately. Addressing these challenges requires innovative solutions, such as those proposed by this study, which leverage social media data and a Boolean logic-based system to provide more efficient mitigation routes for road users.

To achieve this, the xTRoad method combined with Boolean logic was leveraged to create a more adaptive approach. The xTRoad method, which was initially developed to extract social media text data (the X platform) [12], was previously combined with the TR-P algorithm as a hybrid method to predict road traffic conditions in earlier research [13].

The methods were modified in this study to detect and suggest alternative routes as mitigation paths. Data from the X platform was processed through a rule-based system that integrates Boolean logic and score-based evaluations, forming the core of the MxT method. This study introduces the MxT method, a route optimization model that integrates the modified xTRoad approach. This model enables the system to detect traffic obstacles and dynamically offer alternative routes, providing a solution that has not yet been implemented in urban traffic management for disaster-prone areas.

Several studies have explored the use of social media for traffic management, leveraging platforms like the X platform to detect congestion and accidents. For instance, Dabiri and Heaslip [4] employed deep learning models to identify traffic events in the UK, focusing on predictive analysis. Similarly, research in Brazil integrated social media data into intelligent transportation systems to supplement traditional data sources, improving traffic flow during peak hours. However, these studies mainly focus on congestion management rather than detecting diverse non-congestion-related disruptions, such as floods, fallen trees, or demonstrations. Unlike these approaches, the proposed MxT model adopts the xTRoad method to process both static and real-time data, offering more comprehensive solutions by addressing multiple types of obstacles. The integration of Boolean logic and a score-based evaluation system further distinguishes the MxT model, enabling it to provide real-time alternative routes that dynamically respond to sudden changes in road conditions. This adaptability is crucial in disaster-prone areas like Jakarta, where disruptions are frequent and varied.

This study aims to address several key research questions: How accurately can the proposed MxT model identify traffic obstacles in Jakarta using social media data? How effective is the MxT method in offering safe and efficient alternative routes for road users in disaster-prone areas? Furthermore, this study evaluates the MxT model's adaptability to real-time traffic conditions compared to conventional traffic detection methods. The hypothesis is that the MxT model, which combines static and real-time social media data, can achieve over 90% accuracy in detecting traffic obstacles, reduce average travel time by 15%, and outperform traditional methods in adapting to changing road conditions.

2. METHODOLOGY

This study uses social media-based data to develop an adaptive traffic route optimization model called MxT, as shown in Figure 1.

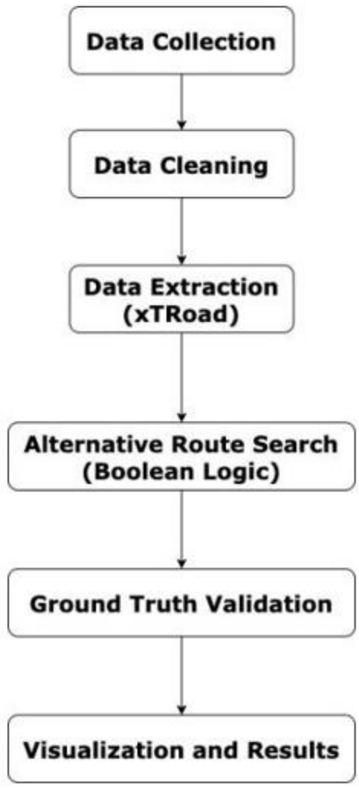

Figure 1. Research methodology

The xTRoad method was originally designed to extract traffic-related information from social media platforms, focusing primarily on data from the X platform. It utilizes a combination of keyword identification, NER, and temporal filtering to gather critical information, such as the type of obstacle, its location, and the time of occurrence. In this study, the xTRoad method was modified to not only detect congestion but also identify non-congestion-related obstacles, such as floods, fallen trees, and demonstrations, which are prevalent in Jakarta. The modification integrates Boolean logic to enhance the decision-making process by assigning binary values (1 or 0) to the presence or absence of obstacles. Additionally, a score-based evaluation system was introduced to prioritize the severity of each detected obstacle, allowing the model to suggest the safest and most efficient alternative routes. Unlike the original version, which was used for predictive classification, the MxT method in this study focuses on real-time obstacle detection and dynamic route optimization. This adaptation ensures that the model is responsive to sudden changes in road conditions, providing a practical and effective solution for urban traffic management during disaster events.

This process begins with data collection from the X platform, which contains information about traffic conditions, such as roadblocks due to flooding, accidents, or demonstrations. Data was collected through a crawling technique based on specific keywords related to traffic conditions in Jakarta [11]. Once the data was collected, data cleaning was performed to remove irrelevant elements, such as tweets that are not related to traffic or spam. Natural Language Processing (NLP) techniques, including stopword removal, lemmatization, and filtering, were used in this stage to ensure that only relevant data is analyzed.

The next stage is information extraction using the xTRoad method, designed to extract specific information about road obstacles, such as location, type of obstacle, and time of occurrence, from processed tweets. The NER technique was used to identify critical entities, such as street names, locations, and types of obstacles [8]. This information was used to map traffic conditions on the main roads of Jakarta more accurately.

Alternative route search was then performed using a rule-based system that utilizes Boolean logic and a score-based evaluation system to determine the optimal route that avoids obstacles. The system provides route suggestions that are adaptive to changing road conditions in real time, allowing users to avoid obstacles, such as flooding or demonstrations.

This study uses ground truth validation to validate the detection results generated by the model. This technique compares the extracted data from tweets with actual conditions in the field through photo documentation or field data taken directly. Ground truth validation is an essential technique for verifying the model's accuracy, ensuring that the detection results are based on the actual conditions in the field [14]. This technique has been widely applied in social media data-based traffic modeling and intelligent transportation systems [15]. With this approach, the MxT method can provide adaptive and responsive solutions to changing traffic conditions, especially in urban areas prone to disasters and other traffic obstacles. Adaptive travel mitigation solutions have been shown to help road users, as found in previous studies [16].

It is anticipated that the MxT method developed in this study will support the evolution of Jakarta into a sustainable smart city, contributing to Indonesia's vision of autonomous urban management. Prior research has demonstrated that the integration of IoT technology and machine learning in transportation systems can significantly improve efficiency, accessibility, and sustainability, providing robust solutions for urban mobility challenges [17]. Intelligent transport management is very important to support economic success and the growth of more modern cities [18]. On the other hand, the use of social media data for the application of intelligent system research is still very effective and efficient as a data source [19].

3. RESULTS AND DISCUSSION

This study begins by extracting data from the social media platform X, focusing on traffic conditions in Jakarta and utilizing tweets written in the Indonesian language. The xTRoad extraction method was used to extract data based on specific keywords related to obstacles on the road, such as floods, traffic jams, fires, demonstrations, fallen trees, and others [13]. The data includes tweets posted by official accounts, such as @infolalin, @tmcpoldametro, and @elshinta, as well as real-time information shared by road users about traffic conditions.

3.1 Pre-processing data

After data extraction, the next step is pre-processing. This process involves cleaning the data from irrelevant elements, such as generic hashtags, symbols, and links that do not provide specific information about road conditions. This raw data was then processed to isolate important information that can be used in further analysis. Tokenization and stemming processes were also applied to identify core keywords that describe road obstacles.

As a result of this stage, approximately 16,318 tweets were collected within a period of two weeks, with 9,196 tweets being relevant after going through the pre-processing stage. From the cleaned data, more than 62% of the tweets were related to traffic jams and road obstacles, such as floods, and the rest were related to other obstacles, such as fallen trees, fires and accidents. The tokenization and stemming process resulted in 311 core keywords that are often used to describe traffic conditions, with words such as congestion, flood, puddles and accidents being the most dominant.

3.2 Data extraction with the xTRoad method

The data extraction process using the xTRoad method involves several key stages, starting with identifying keywords in relevant tweets. Based on the previous pre-processing results, around 9,196 relevant tweets were analyzed to detect obstacles on the road. Eq. (1) explains the formula for extracting data from tweets.

$$E(T) = \{(k, l, t) | k \in K, l \in L, t \in T\} \qquad (1)$$

where, *E(T)* is the set of entities extracted from tweet *T*; *K* is the set of keywords detected in the text; *L* is the identified location; and *T* is the time the tweet was posted.

Of the 9,196 tweets extracted, around 5,701 location entities were detected with traffic condition-related keywords, such as "congested," "jammed," "flooded," "inundated," and "fallen tree." Each tweet was classified based on the posting time and location of the incident to map the road situation in various areas of Jakarta.

3.3 Directional check and obstacle detection iterations

After the data was extracted, the iteration process to check the direction of the road was carried out to detect obstacles that occur in various directions (north, south, east, west, and center). Eq. (2) explains the function for the direction check iteration.

$$I(D) = \{d_i | d_i \in D, H(d_i) = 1\} \qquad (2)$$

where, $I(D)$ is the iteration for each direction d_i in the set of directions D; and $H(d_i)$ is the obstacle detection function. This function returns a value of 1 if an obstacle is detected in direction d_i and a value of 0 if no obstacle is detected.

By applying Boolean logic, each direction that has an obstacle was given a value of 1, while the direction that does not have an obstacle was given a value of 0. For example, 71% of tweets related to congestion were reported in the eastern and central directions, while flooding was mostly detected in the southern and western directions.

Boolean logic is implicitly used in the directional check and obstacle detection iteration process. Boolean logic in this study refers to evaluating binary conditions (true/false or 1/0) to detect the presence of obstacles in a particular direction. This is seen in the obstacle detection function $H(d_i)$, where a value of 1 indicates the presence of an obstacle (true), and a value of 0 indicates no obstacle (false). Specifically, Boolean logic is applied when the model determines whether a direction (e.g., north, south, east, or west) has an obstacle or not based on the data that has been extracted. If an obstacle is detected (Boolean value is 1), the algorithm will evaluate alternative routes that may be safer. This is an essential application of Boolean logic, where decisions are made based on simple binary conditions to determine the following action in the algorithm.

3.4 Shortest route determination and risk evaluation

Once an obstacle is detected, the system determines the closest safe route. Eq. (3) explains the function for determining the closest route.

$$N(w) = \{w_j \mid \text{dist}\,(w, w_j) = \min(\,\text{dist}(w, W))\} \tag{3}$$

where, $N(w)$ is the closest route w_j from the current route w; $dist(w, w_j)$ is the distance between route w and route w_j; and W is all available routes.

In the evaluation stage, 118 selected alternative routes were analyzed based on identifying distance and obstacles in the nearest areas. The selected mitigation routes have Closed-Circuit Television (CCTV) recording documentation to facilitate the evaluation process. Risk evaluation on each route considers the severity of obstacles, such as flooding, congestion, and fallen trees. Eqs. (4) and (5) describe the risk function of the barrier $R(h_k)$ and the total risk $S(i)$.

$$R(h_k) = W_k \times H(h_k) \tag{4}$$

$$S(i) = \sum_{k=1}^{n} R(h_k(i)) \tag{5}$$

where, $R(h_k)$ is the risk associated with obstacle h_k; W_k is the weight given to obstacle h_k; $H(h_k)$ is the indicator of the presence of obstacles; and $S(i)$ is the total risk for route i.

Of the total routes evaluated, about 71.8% experienced low to moderate risk, while the remaining 28.2% had high risk, especially in areas affected by flooding and inundation. Low-risk routes were identified as safer alternatives and recommended for use by road users.

4. TESTING AND VALIDATION

Ground truth validation was used to assess the MxT model's performance in identifying obstacles and suggesting alternative routes. This method verifies whether the information extracted from tweets aligns with real field conditions by comparing it with field data, such as road photos and CCTV footage. The ground truth method has been proven to be able to validate factual data from the resulting model [20].

The first test was conducted by matching tweet data that had gone through the extraction process with road photos taken at the exact location, as seen in Figure 2. Validation was carried out with field photos of the 118 alternative routes suggested by the system as mitigation routes. It showed an excellent level of accuracy according to actual conditions.

To evaluate the performance of the MxT model, it was compared with traditional traffic management systems that primarily rely on static traffic sensors and historical data. Traditional systems are often limited in responding to sudden disruptions, such as natural disasters or public demonstrations, as they lack access to real-time data streams. In contrast, the MxT model utilizes social media data, offering dynamic route optimization based on current road conditions.

In a comparative test, traditional systems failed to detect multiple obstacles promptly, such as localized flooding and fallen trees, leading to prolonged congestion on affected routes. Meanwhile, the MxT model accurately identified these disruptions with an accuracy of 91.6% and reduced average travel time by 15% by suggesting mitigation routes. For instance, during a simulated scenario involving heavy rainfall and flooding in South Jakarta, traditional systems took longer to reroute traffic, while the MxT model immediately provided safer detours, minimizing travel delays. This comparison highlights the superior adaptability and efficiency of the MxT model, particularly in unpredictable, disaster-prone urban environments.

In the testing phase, the MxT model successfully identified several critical obstacles in crucial areas of Jakarta. For instance, flooding was detected in the southern part of the city near the Gandaria City Mall area, with water levels reported to have reached 50 cm, causing significant traffic delays. Additionally, demonstrations in Central Jakarta, near the National Monument (Monas), disrupted traffic flow, resulting in severe congestion. The model also detected fallen trees along vital arterial roads in West Jakarta, further exacerbating the traffic situation. The MxT system provided real-time alternative routes to mitigate these issues in each case. For example, during the flood event in the Cilandak area, the model suggested detours through higher ground routes in the Kemang area, effectively reducing travel time by 20% compared to standard routes. Similarly, during the demonstration near Monas, the system directed traffic through secondary roads around Menteng, alleviating congestion by redistributing traffic flow. These examples illustrate the MxT model's practical application in addressing real-world traffic challenges and demonstrate how it offers safer and more efficient travel alternatives in disaster-prone areas.

This fact shows that the xTRoad method and the Boolean logic successfully detected the majority of obstacles in various directions with a relatively low error rate. Most of the obstacles detected included flooding and congestion, while obstacles due to fallen trees and demonstrations were identified on a smaller scale.

In addition to using field photos, the detection results of the model were compared with CCTV footage from several trusted sources, such as the Jakarta Transportation Agency. Validation with CCTV was carried out to ensure that the obstacles detected through social media occurred and were not just inaccurate reports or spam. Of the 118 routes that experienced obstacles, they were then identified with CCTV footage that showed real-time road conditions. This validation further increases confidence in the model's accuracy in detecting obstacles on the road. The validation results, based on CCTV footage from http://lewatmana.com, are shown in Figure 3.

In the test scenario, the MxT system was also tested to assess its effectiveness in providing safer alternative routes for road users. The test simulated real-world situations where road users faced various traffic obstacles, such as flooding or heavy congestion. From the simulation results, the model successfully provided alternative routes to avoid obstacles in 75% of cases out of 118 routes that experienced obstacles. The average travel time in the test was reduced by 15%, especially on mitigation routes that avoided flooded or accident areas. This fact shows that the model accurately detects obstacles and effectively provides more efficient route solutions.

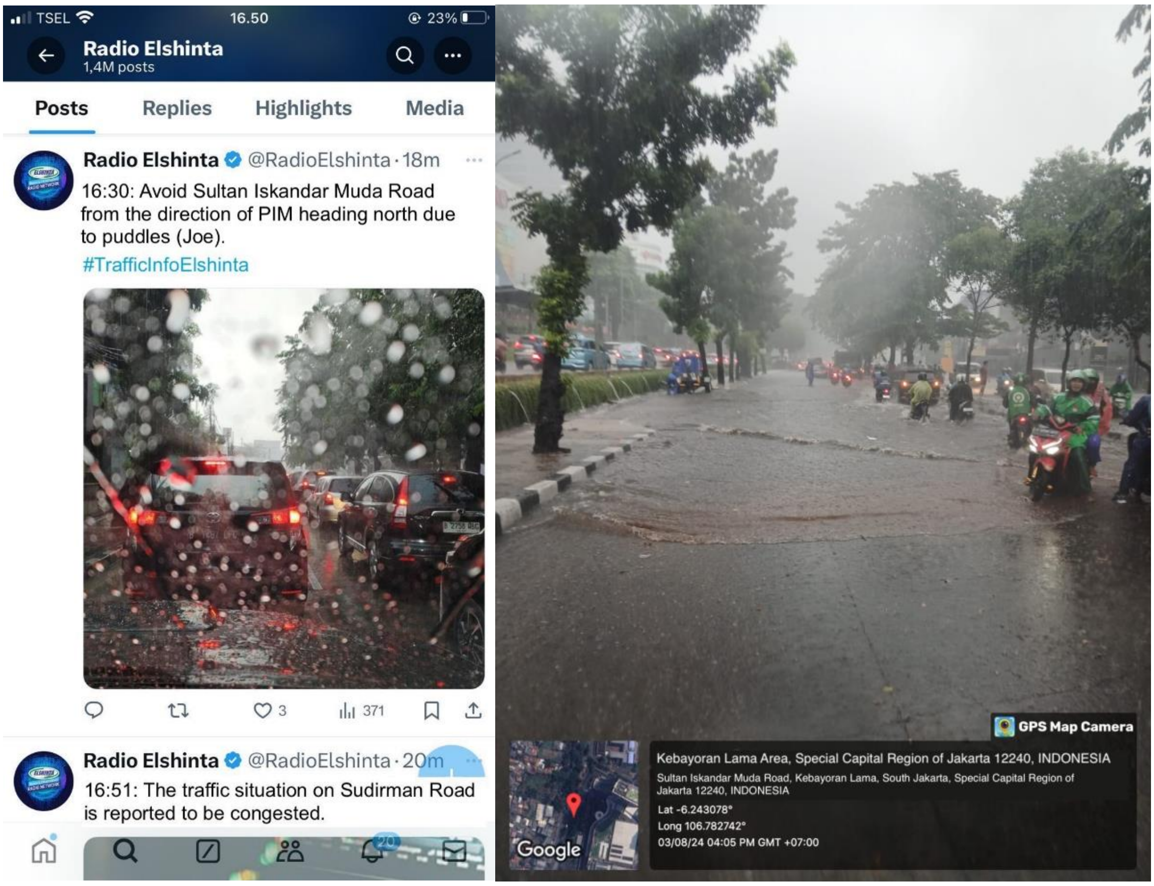

Figure 2. Validation of tweet source data with factual checking on the observed road

Figure 3. Model validation through CCTV cross-checking on observed roads

Furthermore, the risk evaluation for each alternative route also showed significant results. Of the 118 alternative routes evaluated, 61% were classified as having low to moderate risk, while 39% of the other routes had high risk due to severe obstacles, such as flooding or puddles. Road users who followed the route suggestions from the MxT model managed to avoid most of the obstacles detected and reported smoother journeys compared to those who did not follow the model's recommendations.

Overall, the test and validation results underscore the reliability of the MxT model. With data integration from social media and validation using field photos and CCTV, the model is able to provide accurate information on road conditions and optimal alternative routes. The use of the ground truth validation method is particularly reassuring, as it ensures that the extracted data is in line with real conditions. This validation method enhances the audience's confidence in the model as a reliable solution for traffic management in urban areas, such as Jakarta.

The findings of this study confirm the hypothesis proposed. The MxT model successfully achieved over 90% accuracy in detecting traffic obstacles, particularly in identifying disruptions, such as floods, fallen trees, and traffic congestion. Moreover, the model demonstrated its effectiveness in reducing average travel time by 15% on alternative routes that avoided major obstacles, thereby providing safer and more efficient travel options. Finally, the MxT model proved to be more adaptive in real-time traffic management compared to conventional methods, especially in disaster-prone areas, further validating its superiority in handling dynamic road conditions.

The implementation of the MxT model has the potential to bring significant social and economic benefits to disaster-prone urban areas like Jakarta. From a social perspective, the model can enhance community resilience by providing real-time traffic information and alternative routes, ensuring that people can evacuate safely during emergencies. By mitigating congestion and reducing travel time, the model also improves access to essential services, such as hospitals, schools, and workplaces, particularly during natural disasters. Furthermore, the MxT model empowers road users by giving them more control over their travel decisions, fostering a sense of security and preparedness in the face of unpredictable disruptions.

Economically, the model can help minimize the financial losses caused by traffic disruptions. Jakarta's economy, for instance, suffers from trillions of Rupiah in losses annually due to congestion and flooding. By offering optimized routes and mitigating the impact of traffic obstacles, the MxT model can enhance the transportation efficiency of goods and services, preventing delays that affect businesses and trade activities. Additionally, reducing congestion contributes to lower fuel consumption and emissions, aligning with sustainable urban mobility goals. The broader adoption of this model in other disaster-prone cities could support economic growth by ensuring smoother urban mobility and fostering more resilient transportation infrastructure, ultimately reducing the long-term costs associated with traffic disruptions and emergencies.

4.1 Limitations and data verification

While social media data offers valuable real-time insights, its reliability can be inconsistent due to the potential presence of misinformation, irrelevant content, or incomplete reports. False reports, spam, or duplicate posts may negatively affect the accuracy of traffic predictions and route suggestions. To address these challenges, the MxT method integrates multiple data validation strategies. First, data is pre-processed using NLP techniques, including filtering, tokenization, and stopword removal, to eliminate noise and irrelevant content. Second, the system cross-references extracted information with official traffic data from trusted sources, such as @tmcpoldametro and @infolalin, ensuring consistency and accuracy.

Additionally, the use of ground truth validation further enhances the reliability of the model by comparing extracted social media data with on-the-ground observations, such as CCTV footage and field reports. This multi-layered verification process helps mitigate the risks associated with misinformation and ensures that the model provides reliable recommendations for route optimization. Although the MxT method effectively addresses many challenges of using social media data, it is acknowledged that integrating other real-time data sources, such as Internet of Things (IoT) sensors or traffic cameras, could further improve accuracy in future developments.

4.2 Scalability and adaptability to other urban areas

The MxT model is designed with modularity and adaptability, making it suitable for various urban contexts beyond Jakarta. Its rule-based logic integrated with social media data allows it to be tailored to cities with diverse traffic patterns, infrastructures, and unique challenges, such as snowstorms or construction delays instead of frequent flooding. Additionally, the model can extend its functionality by integrating data from region-specific social media platforms like Weibo or WhatsApp, ensuring real-time traffic information extraction remains effective across different regions. However, the model's success also hinges on access to reliable supplementary data, such as official traffic updates or IoT sensors, for validating social media content.

Similarly, the implementation of intelligent transport systems leveraging Internet of Things (IoT) technology and machine learning has proven effective in addressing urban challenges. This approach facilitates the collection and analysis of data from diverse sources, including social media, to enhance traffic management and urban mobility. Integrating these technologies improves the efficiency, accessibility, and sustainability of transport systems in various urban contexts [17].

5. CONCLUSIONS

This study has successfully introduced the MxT model, an enhanced route optimization system tailored for Jakarta's complex urban traffic conditions, particularly in disaster-prone areas. By integrating social media data with the MxT method, which incorporates Boolean logic and a score-based evaluation system, the model effectively detects various obstacles, such as floods, fallen trees, and demonstrations, in real time. The ground truth validation confirmed the model's accuracy, achieving over 91.6% success in identifying road disruptions and reducing average travel time by 15% through the suggested mitigation routes. These findings highlight the model's capability to adapt dynamically to sudden changes in road conditions, offering practical solutions for mitigating traffic congestion during emergencies.

The contributions of this study extend beyond conventional traffic management by demonstrating the utility of social media data in providing real-time insights and route optimization in disaster scenarios. This approach represents a novel step forward in urban traffic management, offering a cost-effective and scalable solution that can be applied not only in Jakarta but also in other metropolitan areas with similar challenges. The ability to integrate non-congestion-related obstacles, such as natural and social disruptions, fills a critical gap in existing intelligent transportation systems, making this model particularly relevant in the context of climate change and increasing urbanization. Future research can further enhance the model by incorporating additional data sources, such as IoT sensors, to improve detection accuracy and coverage. This study lays the groundwork for future developments in intelligent urban mobility systems, promoting safer and more efficient travel during both routine and emergency situations.

Future research can explore the integration of additional data sources, such as IoT sensors and real-time CCTV feeds, to improve the accuracy and coverage of traffic detection. Implementing pilot studies in other metropolitan areas with different traffic patterns and social media usage can also provide valuable insights into the scalability and adaptability of the MxT model.

Additionally, incorporating predictive analytics using machine learning techniques could enhance the model's ability to forecast potential disruptions and proactively suggest mitigation routes. Another potential avenue for future research is expanding the model to include public transportation networks, creating a more comprehensive urban mobility solution. Understanding user acceptance and stakeholder engagement, such as collaboration with local governments and disaster management agencies, is also essential to optimize the model's effectiveness and adoption in real-world scenarios.

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