Transport and Communications Science Journal, Vol. 76, Issue 01 (01/2025), 79-88

Transport and Communications Science Journal

MACROSCOPIC EVALUATION OF ROAD TRAFFIC SAFETY USING QGIS: A CASE STUDY OF TUYEN QUANG PROVINCE

Vuong Xuan Can[1*], Bui Duy Hien[1,2], Tran Trung Hieu[1,3]

[1]University of Transport and Communications, No 3 Cau Giay Street, Hanoi, Vietnam

[2]DOT of Tuyen Quang, Tuyen Quang city, Tuyen Quang Province, Vietnam

[3]Dong Thai people's committee, An Duong, Hai Phong, Vietnam

ARTICLE INFO

TYPE: Research Article
Received: 31/07/2024
Revised: 19/11/2024
Accepted: 10/01/2025
Published online: 15/01/2025
https://doi.org/10.47869/tcsj.76.1.7

[*] *Corresponding author*
Email: vuongcan@utc.edu.vn; Tel: +84915660966

Abstract. Road traffic safety in Vietnam is one of the top social concerns due to the complicated situation of traffic accidents, requiring in-depth research to find appropriate solutions. Macroscopic evaluation of traffic safety is one of the effective ways to prevent and reduce road traffic accidents. The paper presents a new method based on an Equivalent Severity Score (ESS) to evaluate road traffic safety in an area using a geographic information system (GIS) tool, namely QGIS. The road traffic accident (RTA) data from 2021 to 2023 in Tuyen Quang province, Vietnam, was used to analyze and test this method. First, the RTA data was divided by the administrative units of Tuyen Quang, using several evaluation indicators, including the number of traffic accidents, fatalities, serious injuries, and slight injuries. Then, the ESS was determined based on these evaluation indicators to measure the seriousness of RTA across the administrative units. Finally, the ranking of road traffic safety of administrative units is presented by using QGIS software. From there, the traffic authorities can easily understand areas where RTA occurs more seriously and provide reasonable solutions. The results of the paper will help traffic authorities have more basis in making decisions related to solutions to solve traffic problems not only in Tuyen Quang province of Vietnam but also in other localities.

Keywords: road traffic accidents, QGIS, macroscopic evaluation, road traffic safety

1. INTRODUCTION

Road traffic safety (RTS) is an indispensable part of the sustainable development of a city, a region, a country, and even all humanity. RTS is the happiness for every family, so it always receives the top concern of the whole population. In general, the problem of RTS is very complex and is affected by many factors, including road factors, vehicle factors, human factors, and environmental factors. However, it is usually measured directly based on road traffic accidents (RTA) and their consequences.

The increase in registered vehicles and road mileage has led to a rise in road traffic accidents (RTAs) worldwide. According to World Health Organization (WHO) reports in 2023, there were approximately 1.19 million road traffic deaths in 2021, equating to a rate of 15 deaths per 100,000 population. Around 92% of these fatalities occurred in upper-middle, lower-middle, and low-income countries, with road traffic deaths comprising 44% in lower-middle income, 35% in upper-middle-income, and 13% in low-income countries, respectively [1]. These accidents cost about 3% of annual gross domestic product in these nations. In Vietnam, according to the reports of the National Traffic Safety Committee in 2023, there were over 6.3 million automobiles of all types with an annual growth rate of about 10%; and over 74.3 million motorcycles with an annual growth rate of about 5%. The total length of the road traffic network was 595,201 km in 2022, which includes expressways, national roads, provincial roads, urban roads, and others. Regarding RTA, there were 20,067 traffic crashes, 11,628 deaths, and 15,292 injuries on Vietnam's road networks in 2023, i.e., at least 31 road fatalities and 41 injuries per day. According to the estimates of the World Bank, the economic cost of road fatalities and serious injuries in Vietnam is approximately USD 18.02 billion [2]. To decrease RTA significantly as well as decrease its devastating effect on the lives of people, it is crucial to understand where and when traffic accidents happen frequently throughout the safety evaluation.

Evaluation of traffic safety is one of the important ways to prevent effectively and reduce road traffic accidents because it directly impacts on the decision-making related to road safety. Generally, the evaluation of traffic safety is an examination related to the potential safety issues and the performance of road traffic systems to identify and estimate the effects of the factors on frequencies and severity of RTA considering all road users and opportunities for safety improvements [3]. Hence, many scholars have dedicated themselves to establishing new evaluation methods of traffic safety. In general, evaluation methods using data from RTA can be divided into macroscopic and microscopic approaches [4, 5]. The former refers to evaluating the RTS in certain geographic areas or regions through road traffic accidents and their characteristics, such as socio-economic conditions, demographics, factors of road infrastructure, land use, and so on [5], therefore, several areas with serious accidents can be identified and given priority for the policy and mechanism of safer road treatments. The latter conducts RTA on specific facilities or sections, such as intersections, roadway segments, pedestrian crossings, ramps, etc. Microscopic approaches consider variables aggregated at specific locations (i.e. roadway segments or intersections), including road geometrics, traffic volume, traffic components, etc. This study focuses on the discussion related to macroscopic evaluation approaches and proposes a new method for macroscopic evaluation of RTS based on an Equivalent Severity Score (ESS) and GIS software, namely QGIS. The main objective is to rank the safety of the areas so that decision-makers have a solid basis for setting priorities in ensuring traffic safety.

2. LITERATURE REVIEW

Generally, macroscopic evaluation approaches include both single criteria and multi-criteria methods. Single-criteria methods are based on either absolute indicators (like the number of accidents, fatalities, or injuries) or relative indicators (for example, the number of accidents, fatalities, or injuries per 1,000 people). For instance, authors in [6] used fatality rates per 100,000 vehicles and personal fatality risk per 10 million trips to evaluate the fatality risks of road users in six mid-sized cities in India. They found that fatality rates per 100,000 vehicles for motorized two-wheelers and three-wheeled scooter taxis were 2-3 and 3-5 times higher than that for cars, however, motorized two-wheelers and cars posed a similar risk to society, with three-wheeled scooter taxis representing a slightly smaller risk. The main advantage of these methods is their simplicity, however, the biggest limitation is that they reflect only one specific aspect related to RTA and even a self-contradiction conclusion could have occurred. To overcome the limitations of single-criteria methods, multi-criteria methods have been interested and developed recently. These methods are based on the integration of absolute indicators and/or relative indicators mentioned above, such as the clustering analysis method, grey evaluation method [7-11], fuzzy comprehensive evaluation (FCE) [12, 13], data envelopment analysis (DEA) [14], principle component analysis (PCA) [15], and so on [5]. In [15], the authors used PCA with six relative indicators to rank the traffic safety level of 30 provincial capitals in China from 1990 to 2006. They found that the differences in road safety among cities were comparatively distinct in 2006; the fatalities per number of accidents and mortality were the crucial evaluation indicators for the cities in China. The researchers in [16] utilized the Grey system theory and neural network by integrating three indicators to evaluate RTS for seven cities in China. They revealed that their proposed method was more advantageous than traditional methods with a relative indicator solely. The researchers in [13] used FCE with grey relational analysis through nine indicators to assess and rank the comprehensive risk of traffic accidents in 31 provinces in China. They concluded that their result had great significance for traffic safety measurement and management of an area. The authors in [14] applied DEA to estimate road safety performances of 31 provinces of Iran. Their DEA method used six indicators, including passenger kilometers, number of automobiles, ton-kilometers, population, free/highway length, and speed camera as input variables to obtain three outputs road facilities, injuries, and crashes. They found that the number of fatalities was the most important indicator while population and speed cameras were the less important ones. The majority of these methods are created for distinct purposes, each method has contributed to the development of safety evaluation methods. Besides, the advantages, these methods have certain limitations that restrict their applications. For example, there are factors of subjective experiences and preferences of the researchers in the implementation process. Furthermore, most of these methods have not been integrated with geographic information systems (GIS) to visualize research results. GIS analysis will support traditional time-based analysis, making it easier for engineers and managers to visualize and identify areas of serious accidents on spatial maps. Therefore, it is also necessary to conduct studies related to GIS integration in macroprudential assessment to fill in the gaps of the above methods.

So far, in Vietnam, the main evaluation methods of traffic safety are still based on three indicators, including the number of RTA, fatalities, and injuries. For example, in Circular No. 26/2012/TT-BGTVT of Vietnam Transport Ministry dated July 20, 2012, three absolute indicators including the number of RTA, fatalities, and injuries in 12 months of the year are utilized to identify potential accident points and black spots of accidents; In Circular

No.26/2024/TT-BCA of Vietnam Ministry of Public Security dated June 21, 2024, some relative indicators (e.g., number of RTA per hundred thousand people, number of RTA per ten thousand vehicles, number of RTA per kilometer, etc.) have been added in traffic accident statistical reports to consider as safety coefficients. However, due to the new issuance, there have been no full reports using these indicators to assess safety, nor is there a specific method to integrate these indicators. Absolute indicators make it difficult for us to compare and rank traffic safety among areas [9], leading to difficulties in developing priority plans for ensuring traffic safety. Only a few scholars have been interested in developing macroscopic evaluation methods using new methods. Typically, authors in [17] used a severity index to investigate accident hotspots in Hanoi using the mapping of GIS. However, they did not consider traffic accident ratings in Hanoi areas. In [9], the authors compared and ranked traffic accidents in some Vietnamese urban areas through Gray Relational Analysis. However, their results have not been visualized with graphs and maps like GIS.

3. METHODOLOGY

3.1. Equivalent Severity Scores (ESS)

The absolute indicators including the number of RTA, fatalities, and injuries are commonly used to analyze and evaluate RTS in Vietnam. These absolute and discrete indicators make it difficult to reflect the status of RTS in an area. At the same time, it is also difficult to make rankings and comparisons of RTS between areas. To address these limitations, we often use relative indicators such as the ratio of deaths to accidents, the number of accidents per thousand people, etc.[9]. However, integrating indicators into a comprehensive index to facilitate ranking and comparison of RTS is still a challenge. In this study, a new evaluation index, called Equivalent Severity Score (ESS) is proposed based on the absolute and relative indicators to serve as a basis for ranking and comparing the safety status of areas. ESS is calculated as the following equation.

$$ESS = \frac{SI}{P} \times 10^3 \quad (1)$$

Where, ESS is the equivalent severity score of an area or a region; P is the area population (people); SI is the severity index of the area and it is determined by the following equation.

$$SI = \frac{L+3S+5D}{N} \quad (2)$$

Where, N is the number of years of RTA statistics; L, S, D are slight, serious, and fatal accidents in terms of the period, respectively; “1, 3 and 5” are equivalent weights provided for slight, serious, and fatal accidents, respectively [18]. A fatal accident is equivalent to five slight injuries and a serious injury is equivalent to three slight injuries. The larger the equivalent severity score of an area, the higher the severity of RTA in the area.

3.2. Integration of ESS and QGIS

Quantum GIS, also known as QGIS, is a free open-source GIS software that enables users to create maps with the help of core functions and free open-source plugins. QGIS can be run on many distinct types of operating systems (Windows, iOS, and Linux) and supports numerous vector, raster, and database formats [19]. GIS in general and QGIS in particular enable us to collect, store, manipulate, query, analyze, and visualize spatial data which plays an important role in the analysis and evaluation of road traffic safety. Hence, QGIS is a very powerful tool for conducting spatial-temporal analysis, including road traffic safety.

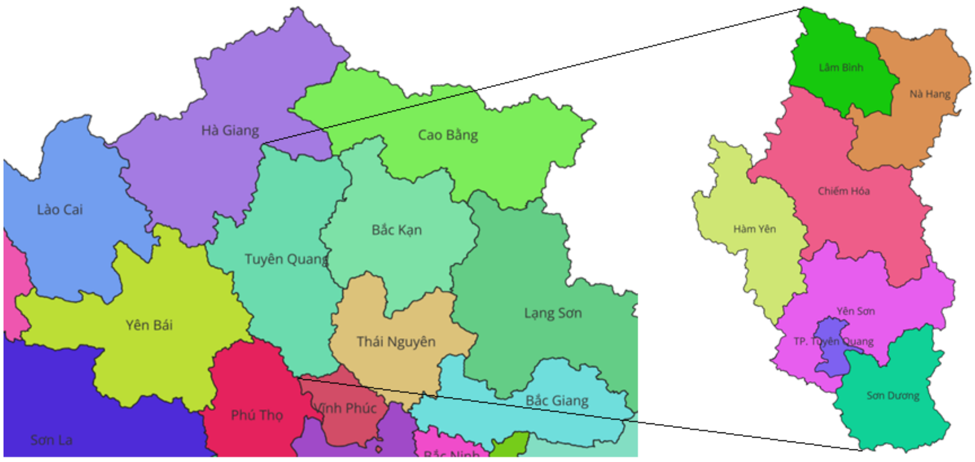
In general, the steps of QGIS consist of determining the project objectives, collecting and converting data, data storage, data analysis, and result visualization. In this study, the administrative boundaries as objects assessed for safety are downloaded from GADM [20] and adjusted to suit reality through digitization skills and OpenStreetMap integrated into QGIS. Accident data and ESS index are imported into QGIS at the data storage step to serve as a basis for analysis and result visualization.

4. CASE STUDY OF TUYEN QUANG

4.1. Study data

In this study, Tuyen Quang province is selected to evaluate the traffic safety of its districts. Located in the northeastern part of Vietnam to the northwest of Hanoi (Figure 1), Tuyen Quang is a mountainous province that spans 5,867.3 square kilometers. The population of Tuyen Quang reached 805,780 in 2022 with 13.88% of its population living in urban areas and the remainder residing in rural areas. Tuyen Quang province is also known for its diverse community with different ethnic groups, such as Kinh, Tay, Dao, San Chay, H' Mong, etc. The road traffic network of Tuyen Quang province has a total of 6,138 km of roads, including national roads (563km), provincial roads (451km), urban roads (304km), countryside roads (1,141km), and others (3,678km).

To assess the RTS of administrative units (or districts) in Tuyen Quang, this study uses three different databases. First, the borders of the administrative units are provided in a shapefile format. The seven administrative units in Tuyen Quang are Lam Binh, Na Hang, Chiem Hoa, Ham Yen, Yen Son, Tuyen Quang City, and Son Duong (Figure 1). Second, a database of RTA for the years 2021 to 2023 is supplied by the Tuyen Quang Department of Transport Police. Third, data on the population in these administrative units is included to analyze the RTS as well.



Source: Authors extracted from QGIS

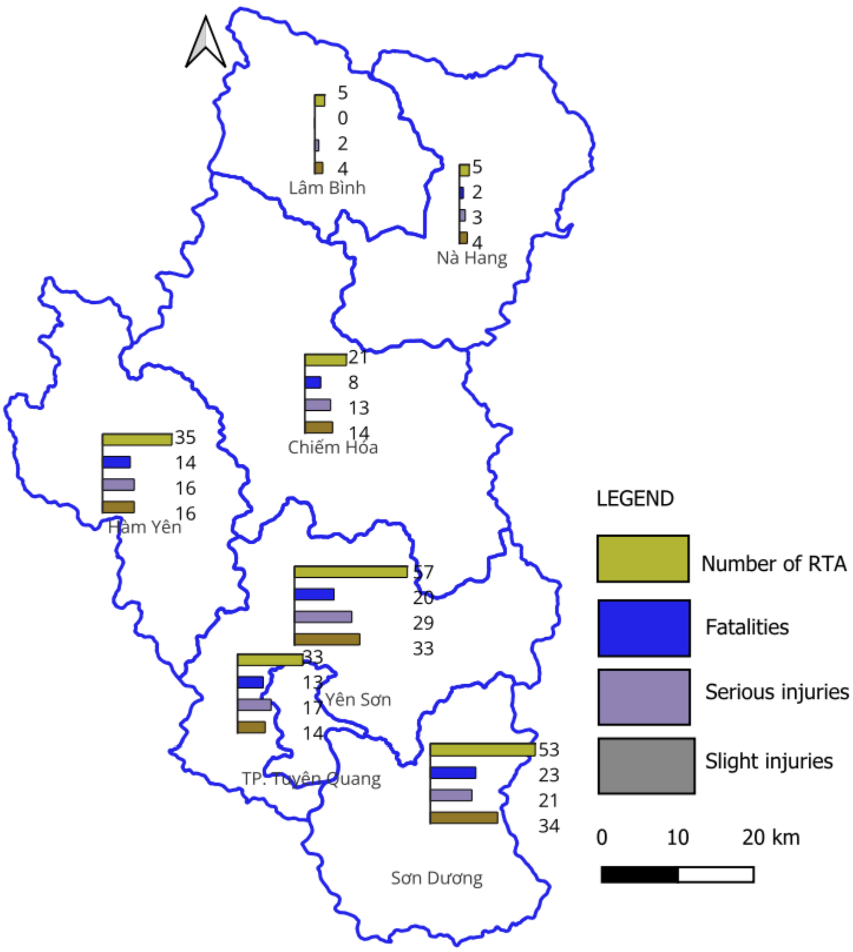
Figure 1. Administrative map of Tuyen Quang province.

There were 209 cases of RTAs recorded on the road network of Tuyen Quang from 2021 to 2023. The RTA database is available in an Excel file that includes key parameters such as date and time, accident location, and the number of injuries.

4.2. Analysis results and discussion

Based on traffic accident data, and map data combined with Equation (1) and Equation (2), through QGIS software (Version 3.36.0), we can easily achieve the results shown in Figures 2 to 4 below. From these figures, we can visualize the evaluation indicators in both absolute and relative, corresponding to the districts of Tuyen Quang province.

Figure 2 reveals that Yen Son and Son Duong are the two districts with the highest absolute indicators (number of RTA, fatalities, serious injuries, and light injuries). In contrast, the Lam Binh and Na Hang districts have the lowest absolute indicators. However, if we only rely on these absolute indicators, sometimes it does not reflect the whole picture of accidents in the districts. The ranking of road traffic safety of the districts in Tuyen Quang based on absolute indicators is shown in Table 1. The results of the ranking of safety status in Table 1 indicates that there are differences between the ranking results of single-criteria methods using absolute indicators. Simultaneously, it is easy to appear in the same grade due to the same value of the absolute indicator.



Source: Authors extracted from QGIS

Figure 2. Absolute indicators of RTA in the districts from 2021 to 2023.

Table 1. Ranking of road traffic safety based on absolute indicators.

Districts	Population (people)	Ranking using absolute indicators			
		Number of RTA	Fatalities	Serious injuries	Slight injuries
Lam Binh	32110	1	1	1	1
Na Hang	44599	1	2	2	1
Chiem Hoa	131042	2	3	3	2
Ham Yen	125132	4	5	4	3
Yen Son	179194	6	6	7	4
Tuyen Quang city	107914	3	4	5	2
Son Duong	189335	5	7	6	5

To overcome the limitations of absolute indicators in Table 1, we can replace them with relative indicators, as shown in Figure 3 and Table 2. Figure 3 with relative indicators provides a clearer view of the accident situation in districts according to the population (number of RTAs per 1000 people, fatalities per 1,000 people). Using absolute indicators for comparison, the number of RTAs in Yen Son is 11 times higher than in Lam Binh and Na Hang. However, with relative indicators, such as the number of RTAs per 1,000 people, it is only 2.86 times higher in Na Hang. When comparing the number of fatalities, except for Lam Binh, where no deaths occurred, the other districts show little variation. Although the number of accidents in Na Hang is low, the risk of death in an accident is as high as in other districts. The ranking of road traffic safety in the districts of Tuyen Quang, based on relative indicators, is shown in Table 2.

Similar to Table 1, when we use the single-criteria methods of relative indicator (i.e., number of accidents per 1,000 people, fatalities per 1,000 people, and the ratio of fatalities per number of accidents by year), the ranking results of the safety status of the districts are also somewhat different, making it difficult to choose a ranking. Hence, using the ESS as a composite index for ranking will be more comprehensive because it considers absolute and relative indicators.

Table 2. Ranking of Road traffic safety based on relative indicators.

Districts	Ranking using relative indicators			
	Number of accidents per 1000 people	Fatalities per 1000 people	The ratio of fatalities per number of accidents	ESS
Lam Binh	2	1	1	1
Na Hang	1	2	5	2
Chiem Hoa	3	3	3	3
Ham Yen	4	4	5	4
Yen Son	6	4	2	7
Tuyen Quang city	5	5	4	6
Son Duong	4	5	6	5

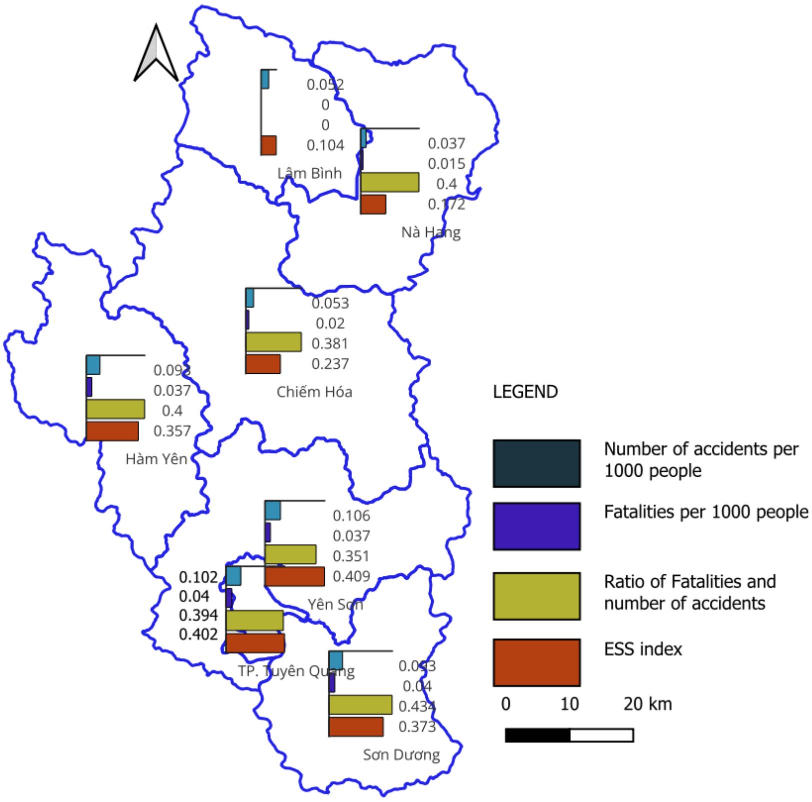
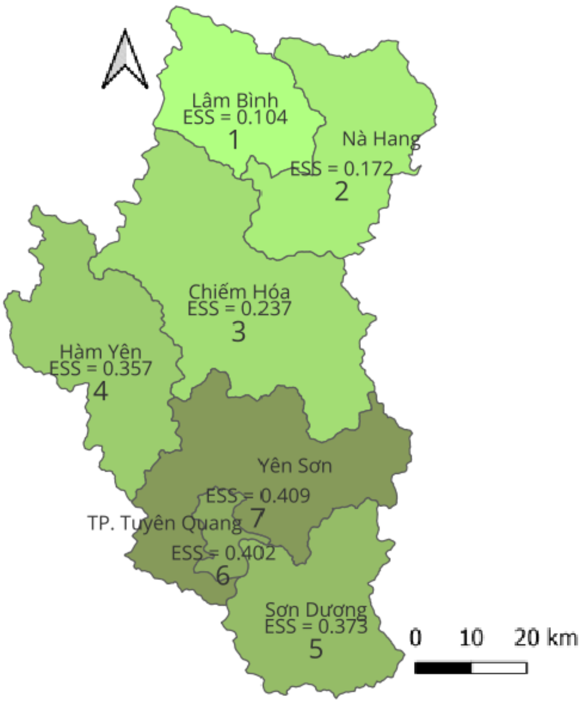


Figure 3. Relative indicators of RTA in the districts (Source: Authors extracted from QGIS).

The integration of ESS of the districts and QGIS is shown in Figure 4 as follows.



Source: Authors extracted from QGIS

Figure 4. The values of ESS and safety ranking of the districts.

Figure 4 shows that the darker the color, the higher the value of the ESS, and the more attention should be paid to traffic accidents. The value of Lam Binh is the lowest and the highest is of Yen Son. The results also show that because the ESS index is based on absolute and relative indicators, it gives more comprehensive results and makes it easier to make decisions related to traffic safety. In the case of districts with small population differences, the number of fatalities with a large weight is the deciding factor for the difference in ESS between districts and accordingly, in the case of limited financial resources, decision makers should prioritize safety solutions for districts with higher ESS index such as Yen Son, Tuyen Quang city and Son Duong. Common safety solutions include engineering (e.g., expanding road lanes, adding traffic safety devices, improving curves and intersections, etc.), enforcement (e.g., traffic enforcement camera) and education. Specific solutions should be based on the characteristics of each accident location in the road network, mainly carried out in micro-safety analyses.

5. CONCLUSION

This study used the ESS indicator on the QGIS map as a method to assess traffic safety. The research results with illustrations in Tuyen Quang showed that there were differences in evaluation when using absolute and relative indicators. The ESS indicator is based on both absolute and relative indicators, so it gives more comprehensive results and makes it easier to make decisions related to traffic safety. This study provides managers with a macro assessment tool in addition to traditional methods to analyze and evaluate the RTS of districts within a province and between provinces in Vietnam. In the next study, the authors will try to expand the ESS based on integrating other criteria such as the number of vehicles, road length in circulation, as well as explore the affecting factors of RTA using QGIS.

REFERENCES

[1]. WHO, Global status report on road safety 2023, World Health Organization, Switzerland, 2023.

[2]. World Bank, Guide for Road Safety Opportunities and Challenges: Low- and Middle-Income Countries Country Profiles, World Bank, Washington DC, 2019.

[3]. S. Mahmud, L. Ferreira, A. Tavassoli, Traditional approaches to Traffic Safety Evaluation (TSE): Application challenges and future directions, Bridging the East and West, (2016) 242-262. https://doi.org/10.1061/97807844798

[4]. U. Brannolte, A. Munch, D.-I. H. Vo, Software-based road safety analysis in Germany, in 4th IRTAD Conference, (2009) 207-218.

[5]. J. Yang, Z. Wu, T. Chen, Review of Urban Road Traffic Safety Evaluation Methods, in the ICTE 2013: Safety, Speediness, Intelligence, Low-Carbon, Innovation, (2013) 2503-2508.

[6]. D. Mohan, G. Tiwari, S. Mukherjee, Urban traffic safety assessment: a case study of six Indian cities, IATSS Research, 39 (2016) 95-101. https://doi.org/10.1016/j.iatssr.2016.02.001

[7]. M. He, X. Guo, Y. Chen, L. Guo, Application of improved gray clustering method in urban traffic safety assessment, Journal of Transport Information and Safety, 28 (2010) 104-107.

[8]. X. C. Vuong, R. F. Mou, T. T. Vu, Analysis and Forecast of Road Traffic Accidents in Vietnam based on Grey BP neural network, in the FAIR, (2018) 35-41.

[9]. X. C. Vuong, T. T. Vu, Comparison and Ranking Road Traffic Accidents Based on Grey Relational Analysis, in 2022 Science and Technology Conference of ITST, Hanoi, Industry and Trade House, (2022) 308-313 (In Vietnamese).

[10]. C. T. Nguyen, X. C. Vuong, T. T. Vu, Exploring Human-error factors contributing to motorcycle accidents in Hanoi city using Grey relational analysis, ASEAN Engineering Journal, 13 (2023) 25-31.

https://doi.org/10.11113/aej.v13.18537

[11]. X. C. Vuong, R.-F. Mou, T. T. Vu, A prediction model of road traffic fatalities in Hanoi using improved grey model GM (1, 1), Science Journal of Transportation, 10 (2020) 43-49.

[12]. X. C. Vuong, T. T. Vu, X. V. Phan, An Identification Method of Traffic Congestion for Urban Road Segments in Vietnam Utilizing Comprehensive Fuzzy Assessment, Tạp chí GTVT, 12 (2020) 137-140.

[13]. Y. Liu, X. Huang, J. Duan, H. Zhang, The assessment of traffic accident risk based on grey relational analysis and fuzzy comprehensive evaluation method, Natural hazards, 88 (2017) 1409-1422. https://doi.org/10.1007/s11069-017-2923-2

[14]. H. Omrani, M. Amini, A. Alizadeh, An integrated group best-worst method–Data envelopment analysis approach for evaluating road safety: A case of Iran, Measurement, 152 (2020) 107330. https://doi.org/10.1016/j.measurement.2019.107330

[15]. S. Ma, C. Shao, Z. Ma, D. Liu, Traffic Safety Evaluation of the 30 Provincial Capital in China Based on Principal Component Analysis, in ICCTP 2009: Critical Issues In Transportation Systems Planning, Development, and Management, 2009, pp. 1-7.

[16]. X. Xu, B. Chen, F. Gan, Traffic safety evaluations based on grey systems theory and neural network, in 2009 WRI World Congress on Computer Science and Information Engineering, IEEE, (2009) 603-607.

[17]. K. G. Le, P. Liu, L.-T. Lin, Determining the road traffic accident hotspots using GIS-based temporal-spatial statistical analytic techniques in Hanoi, Vietnam, Geo-spatial Information Science, 23 (2020) 153-164. https://doi.org/10.1080/10095020.2019.1683437

[18]. K. Geurts, G. Wets, T. Brijs, K. Vanhoof, Identification and ranking of black spots: Sensitivity analysis, Transportation Research Record, 1897 (2004) 34-42. https://doi.org/10.3141/1897-05

[19]. Quantum. QGIS. https://www.qgis.org/, (accessed 30 June 2024).

[20]. GADM. Download GADM data (version 3.6). https://gadm.org/download_country_v3.html, (accessed 30 June 2024).