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EXPLORING HUMAN-ERROR FACTORS CONTRIBUTING TO MOTORCYCLE ACCIDENTS IN HANOI CITY USING GREY RELATIONAL ANALYSIS

Nguyen Chi Trung, Vuong Xuan Can*, Vu Trong Thuat

University of Transport and Communications, Hanoi 100000, Vietnam

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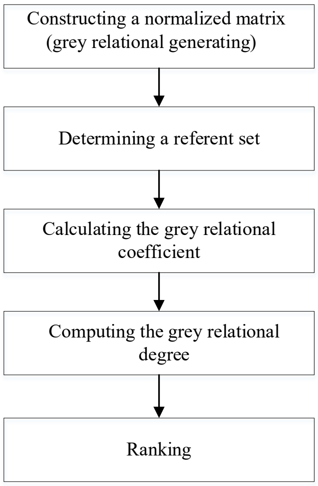
*Corresponding author
vuongcan@utc.edu.vn

Graphical abstract



Abstract

Along with the development of the economy and society and the speedy increasing number of personal vehicles, especially motorcycles, many cities in developing countries like Hanoi (Vietnam) are facing many transportation problems, notably traffic accidents involving motorcyclists. Motorcycle accidents are caused by main human-error factors, and could be considered as the typical grey system with the features of complexity and imperfect information. In this study, a grey relational analysis (GRA) model of the human-error factors is presented to quickly explore the main human-error factors contributing to traffic accidents caused by motorcycles. In this model, the grey relational degree and the grey relational order of each human-error factor also are determined to rank the main contributing human-error factors. Taking the data of road traffic accidents caused by motorcycles in Hanoi, the capital of Vietnam between 2015 and 2017 as experimental data, the grey relational degrees of human-error factors have been analyzed quantitatively through the GRA model. The experimental results show the first three human-error factors include wrong lane shifting, poor road observation, and speeding, respectively. The results also help to conduct effective countermeasures for controlling human errors and reducing road traffic accidents.

Keywords: Road traffic accidents, Grey relational analysis (GRA), Human-error factors, Motorcycle accidents

1.0 INTRODUCTION

Motorcycles are the most frequent means of transportation in Vietnam, Malaysia, Taiwan, and Thailand due to their inexpensive cost and low fuel consumption. For example, in Hanoi City (Vietnam), the ownership and use of motorcycles have experienced a rapidly growing number in recent years. The growth rate of the motorcycles registered is greater than the growth rate of the population. The average growth rate of the motorcycles registered is nearly 7% per year. Up to 2017, there are more than 5.2 million motorcycles registered with over 700 units per 1,000 people [1], carrying over 80% of the trips in this city while public transport only meets about 10-12% of the traffic demand [2, 3]**.** The increase in motorcycle ownership and its use in Hanoi (Vietnam) has led to an increase in road traffic accidents (RTAs) related to motorcycles.

According to World Health Organization (WHO)[4], almost half of all deaths on the world's roads are among road users with the least protection (i.e., motorcyclists, cyclists, and pedestrians). Of these, the majority of road traffic deaths are motorcyclists in South-East Asia, accounting for 43% of all deaths. Vietnam as a country in the South-East Asia region has RTAs involving motorcyclists accounting for over 66.7% of RTAs, and human factors accounting for 71.6% [5]. Hence, motorcycle safety is still a major issue around the world, notably in the South-East Asia region, including Hanoi (Vietnam).

Several previous studies have found that motorcycle accidents have been associated with risky behaviors. They are the combined result of the interaction of internal factors (human factors) and external factors (vehicle and road environment factors) with internal factors being the dominant factor that can explain up to 90% of traffic accidents [6]. Therefore, it is important to understand the human-error factors of motorcyclists to know the causes of traffic accidents and the mechanism of accidents and subsequently establish the countermeasures to improve motorcycle safety.

Up to now, the studies on the human-error factors of motorcycles are still far from universal compared with other road users such as cars and lack general consideration of various contributing factors[7]. Besides, little is known about the human-error factors of motorcyclists in Vietnam and how it contributes to road traffic accidents related to motorcycles. Only a few studies have focused on analyzing one or a few certain related to traffic accident risk of motorcycles in Vietnam's transport context, but it lacks a direct link to motorcyclist accidents. For example, Trinh and Le (2016)[8] examined the relationship between speeding and helmet wearing among motorcyclists. They indicated that the predictors had a significant impact on the intention to speed without helmet wearing. Furthermore, there was a direct link between intention and actual behavior. Vuong et al., (2018)[9] investigated the risk-taking behavior of running a red light at an intersection in Hanoi (Vietnam) and revealed that the running red light behavior of motorcyclists was superior to that of car drivers. Truong et al. (2018)[10] explored the correlations between the use of a phone while riding and other risky behaviors of university students riding motorcycles. They found that the largest occurrence was calling while riding a motorcycle, whereas the lowest prevalence was reckless overtaking. Nguyen-Phuoc et al. (2020)[11] studied risky behaviors of app-based motorcycle taxi riders related to traffic accidents. They showed that the most common risky behavior was using a phone while riding, followed by failing to use turn signals, encroaching car lanes, exceeding the speed limit, running red lights, and carrying more than one passenger. In addition, a few studies have examined the human-error factors in motorcycle accidents through accident analysis. Findings that riding without a helmet, drunk riding, speeding, using a mobile phone while riding, and so on have recently been identified as contributing factors to the accident risk of motorcycles [12-14]. Most findings for human-error factors of motorcyclists in road traffic accidents have been undertaken in developed countries (e.g., the United States, Europe, Australia, etc.). In those countries, motorcycles with larger engine capacities are mainly used for leisure under traffic flow dominated by cars. On the other hand, motorcycles with small engine capacities (50cc-150cc) in Vietnam are used as primary means for daily activities under non-lane-based traffic flow dominated by motorcycles. Hence, human-error factors contributing to motorcycle accident in Hanoi (Vietnam) may differ from those in developed countries [15].

At present, the studies on human-error factors mostly focus on qualitative analysis methods, such as cause and effect analysis, event tree analysis, simulated investigation analysis, and fishbone diagram analysis. Few studies have been conducted to explore human-error factors using quantitative analysis methods such as mathematical statistics analysis with the high requirements for integrity and accuracy data. Besides, it has not clearly expressed a relation between human-error factors and traffic accidents. Hence, it needs to use more effective methods to analyze the occurrence rules of human-error factors of motorcyclists.

Motorcycle accidents are caused by many human-error factors that are influenced by many factors such as road environment, psychophysiological factors, and the interaction between these factors. It is important to explore the main contributing factors to motorcycle accidents to interventions. Numerous researchers have shown that grey relational analysis (GRA) is useful for assessing relationships between contributing factors and systems. Since motorcycle accidents include known information such as the number of accidents, the number of deaths, the number of injuries, and so on, however, there is also unknown information such as the relationship between influencing factors and motorcycle accidents, a priority of influencing factors, etc. Hence, motorcycle accidents can be considered a grey system, and we can use the grey relation analysis of this system to explore the influential factors of motorcycle accidents.

Grey relational analysis as a part of a grey system theory proposed by J. Deng[16], is an interdisciplinary technique that provides a comprehensive evaluation method for an abstract system with limited, incomplete, and uncertain information. The idea of the GRA model is to find a mathematical way to determine a relation between the series that compose a set in the space. So far, the GRA model has been applied successfully in a variety of domains, such as economics, management, decision-making, medicine, prediction, modeling, and data processing [17, 18]. Regarding the road traffic safety sector, some studies have attempted to use the GRA for determining the weights of impact factors and evaluating safety. For example, Lu (2007) [19] applied the GRA model to evaluate the safety effects of traffic safety measures, including infrastructure and advanced driver assistance systems. Ding et al. (2008)[20] used the GRA model to examine drivers' behaviors in a regional traffic accident. Zhang et al. (2011) used the GRA model to investigate prominent factors in traffic accidents in highway work zones [21]. Xi et al. (2009)[22] applied the GRA model to analyze the main reasons in the terms of road traffic accidents in Northeast China. Zeng et al. (2013)[23] proposed an improved GRA model to examine the correlation between five typical traffic accidents (rollover, side collision, co-current collision, rear-end collision, and hitting into fixed things) and the overall traffic accidents in Hubei Province of China. Zhang et al. (2017)[24] applied the GRA model to calculate grey relation degrees of the influential factors in vehicle fire incidents. Liu et al. (2017)[25] used the GRA model to determine the weights of the evaluation indicators in an evaluation system of traffic accident risk in China provinces using a fuzzy comprehensive method. Grdinić-Rakonjac et al. (2021)[26] also used the GRA model to calculate the weights of the indicators of hierarchical road safety indicators. The literature review shows that the GRA model is successfully conducted for calculating the weights of the indicators and assessing road traffic safety in specific territories. However, there seems to be a lack of the GRA model-related research developed specifically for accident analysis as well as safety assessment involving motorcycles, which are commonly used in developing countries like Vietnam. In this study, we attempt to use the GRA model to explore the main human-error factors of motorcycle accidents in Hanoi City, the capital of Vietnam.

The remainder of this paper is structured as follows. Section 2 describes the methodology. The experimental and discussion are presented in Section 3. Section 4 gives some conclusions and future work.

2.0 METHODOLOGY

aGrey system theory was firstly proposed by J. Deng[16] to abstract model a system for which the information is limited, incomplete, and characterized by random uncertainty. In general, a system is considered a grey system when the relevant information is not fully known [27, 28]. The methods of grey system theory include grey system and control, grey modeling (GM), and grey relational analysis (GRA). Of these, grey system and control enriches the field of systems and controls and provides a valuable complement to conventional methods[16]. Grey systems generally refer to systems, objects, or concepts whose outer boundaries are well-defined but whose interior is uncertain or ambiguous, while fuzzy mathematics is the opposite, i.e. refers to systems, objects, or concepts whose internal boundaries are well-defined but external boundaries are not clearly defined [19]. Meanwhile, GM is often used to model systems with limited data. Forecasting is one of the popular applications of the first-order grey model, denoted by GM (1,1)[29, 30]. The GRA is used to address problems involving random uncertainty and correlation analysis under a limited sample size and discrete sequential data. The GRA model also can be used to analyze the impact of the factors on the system. The GRA's fundamental idea is to discover a grey relational order that may be utilized to represent the relationship between related components using data series. It is, in fact, a quantitative analysis method for ambulatory data[31]. The main process of the GRA is first to convert the performance of all alternatives into a comparable series, the so-called grey relational generating step or normalization step. Next, a reference set (ideal target set) is determined. And then, the grey relation coefficient between all the comparison series and the reference set is calculated. Finally, based on these gray relation coefficients, the grey relationship degree between the reference set and any comparison series also is calculated. If a comparison series is translated from an alternative that has a higher grey relational, it will have a higher effect [32].

The GRA model in this study may be summarized by the following steps (see Figure 1)[19, 25].

- Step 1: Construct a normalized matrix (grey relational generating). From the collected data including n objects with m attributes, we can build a decision matrix as follows:

$$X_i = (x_i(1), x_i(2), \ldots, x_i(m))$$
$$i = 1,2,..,n;\ j = 1,2,..,m \tag{1}$$

The attributes of objects can be different, so it is necessary to perform normalization according to a certain standard. In the GRA model, the decision matrix can be normalized using the following criteria types: larger the better, smaller the better, and nominal the best. In this study, the first rule is used so that the larger assigned weight denotes the greater significance of the object. The normalization equation is as follows:

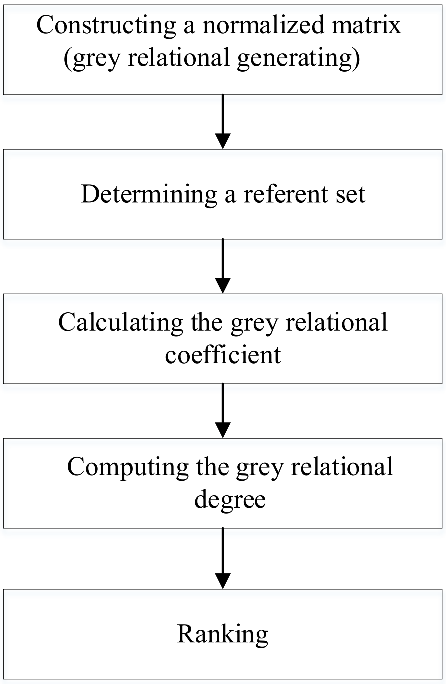


Figure 1. The main process of the GRA

$$x_i^*(j) = \frac{x_i(j) - \min_j x_i(j)}{\max_j x_i(j) - \min_j x_i(j)} \tag{2}$$

Where $\max_j x_i(j)$, $\min_j x_i(j)$ are the maximum value and the minimum value of j-th attribute for i-th object alternative, respectively. The normalized matrix is denoted R as follows:

$$R = \begin{bmatrix} x_1^*(1) & x_1^*(2) & \ldots & x_1^*(m) \\ x_2^*(1) & x_2^*(2) & \ldots & x_2^*(m) \\ \ldots & \ldots & \ldots & \ldots \\ x_n^*(1) & x_n^*(2) & \ldots & x_n^*(m) \end{bmatrix} \tag{3}$$

- Step 2: Determining a referent set. The reference set for the normalized matrix depicts the virtual ideal set and is formed from the ideal values of the attributes. The maximum or minimum value depends on the research objective. The values of the normalized matrix will be scaled into [0,1]. If the value of an object alternative tends to 1 more than others, that means that the value is one of the best attributes. In a road traffic safety issue, a higher weight represents a larger influence, the reference set in this study is built from the maximum values. The reference set is described as follows:

$$X_0 = (x_0(1), x_0(2), \ldots, x_0(m))$$
$$X_0 = (1, 1, \ldots, 1) \tag{4}$$

- Step 3: Calculate the grey relation coefficient. After the reference set is built, the grey relation coefficient is calculated by measuring the distance of each object value from the reference set as shown in the following equation.

$$\gamma_{0i}(j) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(j) + \zeta\Delta_{\max}} \quad (5)$$

Where, $\gamma_{0i}(j)$ is the grey relation coefficient; $\Delta_{0i}(j)$ is difference series and is calculated by Equation (6); $\Delta_{\max}$ is the maximum value of difference series, and is calculated by Equation (7); $\Delta_{\min}$ is the minimum value of difference series is calculated by Equation (8), and ζ denotes the distinguishing coefficient in the range of [0,1] and generally takes on the value of 0.5.

$$\Delta_{0i}(j) = \left| x_0(j) - x_i^*(j) \right| \quad (6)$$

$$\Delta_{\max} = \max_i \max_j (\Delta_{0i}(j)) \quad (7)$$

$$\Delta_{\min} = \min_i \min_j (\Delta_{0i}(j)) \quad (8)$$

- Step 4: Computing the grey relation degree. The grey relation degree of each object can be calculated via the following equation:

$$\Gamma_{0i} = \frac{1}{m}\sum_{j=1}^{m} \gamma_{0i}(j) \quad (9)$$

In case the weights of the attributes ($w(j)$) have known, then the grey relation degree can be calculated as follows:

$$\Gamma_{0i} = \sum_{j=1}^{m} w(j).\gamma_{0i}(j) \quad (10)$$

- Step 5: Ranking. We can construct the grey relation order using the size of the grey relation degree. In this study, the GRA model is used to explore the impact of human-error factors of motorcyclists on motorcycle accidents. The degree of impact represents the grey relation degree. The larger it is, the more important its impact, and vice versa. Based on the grey relation degree, we can easily arrange the factors to prioritize the implementation of appropriate countermeasures.

3.0 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Experimental Data

The experimental data set is the data of RTAs caused by motorcycles in Hanoi where motorcycles play an important role in the transportation system. The number of registered motorcycles are increasing quickly from 3.4 million (about 91% of the number of registered motorized vehicles) in 2010 to 5.5 million units (about 89% the number of registered motorized vehicles) in 2017 [33]. As such, the number of registered motorcycles has been increasing by approximately 5% year by year, and the ownership rate reaches over 700 motorcycles per 1,000 inhabitants while the average growth rate of road surface area only is 0.25% per year from 2011 to 2016, public transport system only meets about 10÷12% of traffic demand [2]. Hence, motorcycles are a major factor in fatalities of RTAs in Vietnam.

In this study, a total of 503 cases with 518 fatalities and 233 injuries is collected in the 2015-2017 period as samples to explore the main contributing factors of human errors (see Table 1) [33]. Based on the statistical results of the road traffic accidents involving motorcycles as shown in Table 1, human-error factors of motorcyclists in road traffic accidents are divided into eleven different categories corresponding to the cause of the road traffic accidents. Each factor has three attributes, including the number of accidents, the number of fatalities, and the number of injuries. So we easily get $n = 11$ and $m = 3$. The maximum values of the attributes are 143, 147, and 85, respectively. The minimum values of the attributes are 1, 1, and 0, respectively.

Table 1. The RTA caused by motorcycles in Hanoi in 2015-2017

Human-error factors	Number of accidents	Number of fatalities	Number of Injuries
Poor road observation (X_1)	143	147	53
Wrong lane shifting (X_2)	143	146	85
Wrong overtaking (X_3)	18	19	7
Speeding (X_4)	130	134	59
Careless turning direction (X_5)	24	25	11
Not keeping a safe distance (X_6)	23	24	12
Careless crossing of pedestrians (X_7)	8	8	4
Riding in the opposite direction or forbidden (X_8)	10	11	2
Red light running (X_9)	1	1	0
Not giving way (X_{10})	2	2	0
Drunk riding (X_{11})	1	1	0
Total	**503**	**518**	**233**

3.2 Experimental Results And Discussion

From the original data, we have normalized according to Equation (2), the results are shown in Table 2. For example, the value of X_1 for the number of injuries is equal to $x_1^*(3)$ = (53-0)/(85-0)= 0.624.

Table 2. The result of normalized experimental data

	Normalized value ($x_i^*(j)$)		
	Number of accidents	Number of fatalities	Number of injuries
X_1	1.000	1.000	0.624
X_2	1.000	0.993	1.000
X_3	0.120	0.123	0.082
X_4	0.908	0.911	0.694
X_5	0.162	0.164	0.129
X_6	0.155	0.158	0.141
X_7	0.049	0.048	0.047
X_8	0.063	0.068	0.024
X_9	0.000	0.000	0.000
X_{10}	0.007	0.007	0.000
X_{11}	0.000	0.000	0.000

From Equation (4), we easily have the reference set as follows: $X_0 = (1,1,1)$. The difference series between the normalized value and the value of the reference set also is calculated based on Equation (6). The results are shown in Table 3. For example, the value of X_1 for the number of injuries is equal to $\Delta_{01}(3) = \left|1 - 0.624\right| = 0.376$.

Table 3. The difference series between normalized value and the value of the reference set

	$\Delta_{0i}(j)$				
	Number of accidents	**Number of fatalities**	**Number of injuries**	**Min**	**Max**
X_1	0.000	0.000	0.376	0.000	0.376
X_2	0.000	0.007	0.000	0.000	0.007
X_3	0.880	0.877	0.918	0.877	0.918
X_4	0.092	0.089	0.306	0.089	0.306
X_5	0.838	0.836	0.871	0.836	0.871
X_6	0.845	0.842	0.859	0.842	0.859
X_7	0.951	0.952	0.953	0.951	0.953
X_8	0.937	0.932	0.976	0.932	0.976
X_9	1.000	1.000	1.000	1.000	1.000
X_{10}	0.993	0.993	1.000	0.993	1.000
X_{11}	1.000	1.000	1.000	1.000	1.000

From Table 3, we obtained the minimum and maximum values of the difference series based on Equation (7) and Equation (8), i.e., $\Delta_{\min} = 0; \Delta_{\max} = 1$. And then, the grey relation coefficient and the grey relation degree also are obtained based on Equation (5) and Equation (9), as shown in Table 4. For example, the value of X_1 for number of injuries is equal to $\gamma_{01}(3)$ = (0+1.000*0.5)/(0.376+1.000*0.5)=0.570.

Table 4. The grey relation coefficient and the grey relation degree

	The grey relation coefficient ($\gamma_{0i}(j)$)			Γ_{0i}	**Ranking**
	Number of accidents	**Number of fatalities**	**Number of injuries**		
X_1	1.000	1.000	0.570	0.8568	2
X_2	1.000	0.986	1.000	0.9955	1
X_3	0.362	0.363	0.353	0.3594	6
X_4	0.845	0.849	0.620	0.7715	3
X_5	0.374	0.374	0.365	0.3710	4
X_6	0.372	0.372	0.368	0.3707	5
X_7	0.345	0.344	0.344	0.3444	8
X_8	0.348	0.349	0.339	0.3453	7
X_9	0.333	0.333	0.333	0.3333	10
X_{10}	0.335	0.335	0.333	0.3344	9
X_{11}	0.333	0.333	0.333	0.3333	10

From the grey relation degrees in Table 4, we can easily rank the objects (human errors) in order from the highest to the lowest, indicating that their contribution to the motorcycle accidents in Hanoi in the 2015÷2017 period is descending. The impact order of human errors based on the number of accidents is as follows:

$$X_2 = X_1 > X_4 > X_5 > X_6 > X_3 > X_8 > X_7 > X_{10} > X_9 = X_{11}$$

The impact order of human errors based on the number of fatalities is as follows:

$$X_1 > X_2 > X_4 > X_6 > X_5 > X_3 > X_7 > X_8 > X_{10} > X_9 = X_{11}$$

The impact order of human errors based on the number of injuries is as follows:

$$X_2 > X_4 > X_1 > X_5 > X_6 > X_3 > X_8 > X_7 > X_{10} = X_9 = X_{11}$$

The impact order of human errors based on multiple indexes, including the number of fatalities, the number of fatalities, and the number of injuries is as follows (see the last column of Table 4):

$$X_2 > X_1 > X_4 > X_5 > X_6 > X_3 > X_8 > X_7 > X_{10} > X_9 = X_{11}$$

From the above results, it is shown that when using a single index to sort human errors, there is a certain difference, so the multiple indexes of indicators will give more objective results. The results indicated that the different human errors have different degrees of impact on the occurrence and the severity of accidents. In actual operation, all kinds of human errors should not be taken lightly, and active measures should be taken to reduce them, especially the first three human errors, including wrong lane shifting (X_2), poor road observation (X_1), and speeding (X_4). The results also showed that riding without a helmet and drunk riding were not the main contributors to motorcycle accidents. There was a certain difference with previous studies in developed countries (Lin and Kraus, 2009 [12]; Retting and Rothenberg, 2016 [13]; WHO, 2017 [14]). This can be explained that the helmet and alcohol laws were well implemented in the past time in Vietnam, so motorcycle accidents related to the lack of helmet and alcohol involvement were reduced. However, speeding was a factor consistent with many previous studies (Lin and Kraus, 2009 [12]; Retting and Rothenberg, 2016 [13]; WHO, 2017 [14]). Poor road observation, wrong lane shifting, and speeding were also found to be of great contribution to road traffic accidents in general in Vietnam by some researchers (Mou et al., 2019[1]; Trinh and Trinh, 2009 [34]; Khuat and Le, 2011[35]), but they did not focus on motorcycle accidents.

Main contributing factors in motorcycle accidents, including wrong lane shifting, poor road observation, and speeding, are not only related to safe riding skills, legal awareness, and safety awareness of motorcyclists, but also related to mixed traffic characteristics with the lack of lane disciplines, maneuverability of motorcycles, and other factors. Those also reflected that there was a lack of facilities for motorcycles in Hanoi, Vietnam. Therefore, it is necessary to implement effective measures, such as enforcement, education, and engineering to reduce human errors and improve traffic safety. For example, (1) improving infrastructure for motorcycles by using motorcycle lanes, motorcycle signal lights, motorcycle priority areas, and road lights to reduce errors related to observation, lane shifting, turning direction, etc; (2) Strengthen enforcement of speed limits, alcohol and red light running through traffic police and traffic surveillance cameras; (3) Increasing attention to motorcycles through colors and lights; (4) Increasing road law awareness and driving skills through safety campaigns, the awareness of dangerous situations, and practice of driving skills in a virtual environment.

4.0 CONCLUSION

Human error is one of the main factors causing motorcycle-related road traffic accidents. Understanding these errors will help to understand the mechanisms involved in accidents as well as the basis for recommending appropriate countermeasures. In this study, the GRA model was used to explore the main contributing human-error factors to RTAs related to motorcycles in Hanoi, Vietnam. The results found that the first three human errors, including wrong lane shifting, poor road observation, and speeding were major contributors to motorcycle-related traffic accidents in Hanoi, Vietnam. There was a certain difference in the main contribution factors found in developed countries, such as the lack of helmets, alcohol involvement, and speeding due to the specificity of traffic in Vietnam. Speeding, which was the major contributing factor to motorcycle accidents found in most previous studies, was also found in this study. Wrong lane shifting and poor road observation were found among the few studies on road traffic accidents in general that did not focus on motorcycle accidents.

The findings of this study can help the authorities in Hanoi to pay a special attention to appropriate countermeasures, such as engineering, enforcement, and education, to reduce human errors related to motorcyclists, and reduce RTAs associated with a motorcycle in Hanoi, Vietnam.

Although the results are promising, some limitations may include a limited number of human factors considered, limited statistical year and survey areas, and the lack of other factors (e.g., road surface conditions, weather conditions, traffic conditions, etc.). In future studies, we will consider these factors under the improved GRA model.

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